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The Northern Rockfish

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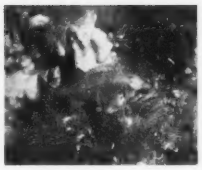
On the cover:
A northern rockfish, *Sebastes polyspinus*, in the Aleutian Islands, photographed from a submersible. NMFS photograph by Robert Stone, AFSC Auke Bay Laboratory.



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The Northern Rockfish, *Sebastes polyspinis*, in Alaska: Commercial Fishery, Distribution, and Biology

DAVID M. CLAUSEN and JONATHAN HEIFETZ

Introduction

The northern rockfish, *Sebastes polyspinis*, is one of the most abundant and commercially valuable members of its genus in Alaska waters. As implied by its common name, this fish has one of the most northerly distributions among the 60+ species of *Sebastes* in the North Pacific Ocean. It ranges from extreme northern British Columbia around the northern Pacific Rim to eastern Kamchatka and the northern Kurile Islands and also north into the eastern Bering Sea (Allen and Smith, 1988; Orlov[1]), but is common only in Alaska waters.

Bottom trawl surveys of the Gulf of Alaska and Aleutian Islands regions indicate that northern rockfish is the second most abundant rockfish species there, surpassed only by Pacific ocean perch, *S. alutus* (Harrison, 1993; Ronholt et al., 1994; Stark and Clausen, 1995; Martin and Clausen, 1995; Martin, 1997). Amongst all species caught in three surveys of each region that were conducted in the 1990's, northern rockfish ranked tenth in average biomass in the Gulf of Alaska, and fourth in the Aleutian Islands.[2] Since 1990, northern rockfish has supported a valuable domestic trawl fishery in Alaska; for the Gulf of Alaska region alone, gross wholesale value of this fishery was estimated at $3.5 million in 1995 and $1.2 million in 1999 (Bibb[3]).

Despite this ecological and commercial importance, little has been published on the biology of northern rockfish or its fishery. The species was first described by Taranetz and Moisev (Taranetz, 1933) based on a specimen from the eastern Bering Sea. The only biological study to deal exclusively with northern rockfish is that of Westrheim and Tsuyuki (1971). Their report presented information on many aspects of northern rockfish biology, including taxonomy, distribution and abundance, size composition, age and growth, and size at maturity. Although this study still provides valuable information, much of it now has to be considered somewhat outdated. The distribution and abundance data came from research

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[1] Orlov, Alexie, Russian Federal Research Institute of Fisheries and Oceanography (VNIRO), 17 Krasnoselskaya, Moscow, 107140, Russia. Personal commun., May 2000.

[2] Based on data in the "RACEBASE" database, the trawl survey database maintained by the NMFS, NOAA, Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering (RACE) Division, February 2000.

[3] Bibb, Sally, Sustainable Fisheries Division, NOAA, Natl. Mar. Fish. Serv., Alaska Regional Office, Juneau, AK. Personal commun., April 1997 and June 2000.

ABSTRACT—*The northern rockfish,* Sebastes polyspinis, *is the second most abundant rockfish in Alaska, and it supports a valuable trawl fishery. Little information is available, however, on either the biology of this species or its commercial fishery. To provide a synopsis of information on northern rockfish in Alaska, this study examined data for this species from commercial fishery observations in 1990–98 and from fishery-independent trawl surveys in 1980–99. Nearly all the commercial catch came from bottom trawling, mostly by large factory-trawlers, although smaller shore-based trawlers in recent years took an increasing portion of the catch in the Gulf of Alaska.*

Most of the northern rockfish catch in the Gulf of Alaska was taken by a directed fishery, whereas that of the Aleutian Islands predominantly came as discarded bycatch in the Atka mackerel fishery. In both regions, most of the catch was taken from a number of relatively small and discrete fishing grounds at depths of 75–150 m in the Gulf of Alaska and 75–175 m in the Aleutian Islands. These grounds, especially in the Gulf of Alaska, are on shallow rises or banks located on the outer continental shelf, and often are surrounded by deeper water. Five fishing grounds were identified in the Gulf of Alaska, and eleven in the Aleutian Islands. One fishing ground in the Gulf of Alaska, the "Snakehead" south of Kodiak Island, accounted for 46% of the total northern rockfish catch in this region.

Analysis of the survey data generally revealed similar patterns of geographic distribution as those seen in the fishery, although some of the commercial fishing grounds did not stand out as areas of special abundance in the surveys. The surveys also found two areas of abundance that were not evident in the fishery data. Relatively few juvenile northern rockfish were caught in any of the surveys, but those taken in the Gulf of Alaska tended to occur more inshore and at shallower depths than adults. Individual size of northern rockfish was substantially larger in the Gulf of Alaska than in the Aleutian Islands according to both fishery and survey data. Analysis of age data from each region supports this, as Gulf of Alaska fish were found to grow significantly faster and reach a larger maximum length than those in the Aleutian Islands. Sex ratio in the Gulf of Alaska was nearly 50:50, but females predominated in the Aleutian Islands by a ratio of 57:43. In both regions, size of females was significantly larger than males.

trawling conducted in the Gulf of Alaska over 30 years ago, and the age results are based on surface readings of otoliths, a technique which is now thought to substantially underage rockfish.

More recent information on northern rockfish can be gleaned from trawl survey data reports such as those referenced in the second paragraph of this section, or from annual stock assessment documents for rockfish (e.g. Heifetz et al., 1999). Also, a population dynamics modeling analysis of northern rockfish in the Gulf of Alaska has been completed to quantitatively assess stock condition of these fish, and this study presents some data on the fishery and on survey results (Courtney et al., 1999). In addition, a limited amount of food habits information is available for northern rockfish in the Gulf of Alaska and Aleutian Islands (Yang, 1993, 1996). Most recently, a small and preliminary genetics study of northern rockfish was conducted to determine if any stock structure for this species was readily apparent (Gharrett et al.[4]). Except for the Courtney et al. (1999) and Gharrett et al.[4] studies, however, none of these recent reports focuses completely on northern rockfish, and none discusses the biology of this species in any detail.

This report provides an updated synopsis of available information on northern rockfish and is based on two major data sources: 1) data collected from the commercial fishery in the years 1990–98 by the National Marine Fisheries Service (NMFS), Alaska Fisheries Science Center's (AFSC) fisheries Observer Program and contained on the Program's "NORPAC" database, and 2) data from various bottom trawl surveys conducted between 1980 and 1999 by the AFSC's Resource Assessment and Conservation Engineering (RACE) Division and contained on their "RACEBASE" database.

[4]Gharrett, A. J., A. K. Gray, S. Lyons, D. Clausen, and J. Heifetz. 2003. A preliminary study of population structure in Alaskan northern rockfish, *Sebastes polyspinis*, based on microsatellite and mtDNA variation. *In* A. J. Gharrett (Editor), Population structure of rougheye, shortraker, and northern rockfish based on analysis of mitochondrial DNA variation and microsatellites: completion, p. 1–16. Juneau Center, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 11120 Glacier Hwy., Juneau, AK 99801.

Figure 1.—The three major fishery management regions that are discussed in this report: Gulf of Alaska, Aleutian Islands, and eastern Bering Sea.

First, we use the fishery data to describe the commercial fishery and to present information on the distribution and biology of northern rockfish. Then, we analyze the survey data to present alternative information on the distribution and biology of northern rockfish and to provide a comparison with the results from the fishery data. As part of the survey analysis, we also present age and growth information for northern rockfish.

This report focuses particularly on northern rockfish in the Gulf of Alaska and the Aleutian Islands regions (Fig. 1). Although the species is also found on the outer continental shelf and slope of the eastern Bering Sea, its abundance there has been very low in trawl surveys (Ito et al., 1999), and commercial catches of northern rockfish in this region have been much less than in the other two regions. Consequently, for northern rockfish in the eastern Bering Sea, only fishery data will be presented in this report, and these data will be analyzed in less detail than those for the Gulf of Alaska and Aleutian Islands. The three regions also correspond to major fishery management regions for Federal waters off Alaska.

Commercial Fisheries

Foreign Fishery

Directed fishing for rockfish in Alaska waters began in 1960 with the first catches by Soviet and Japanese bottom trawlers (Balsiger et al., 1985), and foreign catches of rockfish continued until 1987. Most of the fishery was for Pacific ocean perch, *Sebastes alutus*, and massive fishing effort targeting this species in the 1960's caused a precipitous decline in its abundance throughout Alaska waters that has been well documented (Ito[5]). To what extent the foreign rockfish fishery was also taking northern rockfish, and whether there was directed fishing for this species, is unknown for the years through 1976, as there are no available summaries of northern rockfish catches over this period. Foreign catches of all rockfish were often reported simply as "Pacific ocean perch" (Murai et al., 1981), with no attempt to differentiate species. In other instances, Pacific ocean perch were separated out, but all other *Sebastes* were assigned the category of "other rockfish," and there is still no way to determine the catch of northern rockfish.

With the advent of a substantial NMFS observer program aboard foreign fishing vessels in 1977, enough information on species composition of rockfish catches was collected so that estimates of the northern rockfish foreign catch can be

[5]Ito, D. H. 1982. A cohort analysis of Pacific ocean perch stocks from the Gulf of Alaska and Bering Sea regions. NOAA, Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., Bldg. 4, 7600 Sand Point Way N.E., Seattle, WA 98115. NWAFC Processed Rep. 82-15, 157 p.

made for 1977–87 (Tables 1–3). The relatively large catch estimates for 1977–78 in the Aleutian Islands and 1982–83 in the Gulf of Alaska are an indication that at least some directed fishing probably occurred in those years. Except for reporting the foreign catches in Tables 1–3, however, we have decided to omit the foreign fishery observer data from our analyses and to focus instead on the more recent domestic fishery.

Joint Venture Fishery

A new era in Alaska commercial fishing began in 1976 with the passage of the Magnuson Fishery Conservation and Management Act, later renamed the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA; Anonymous, 1996). This Act gave the United States jurisdiction over all groundfish resources within 200 nautical miles (n.mi.) of its shoreline, and set in place regulatory policies that eventually resulted in domestic fishermen replacing the foreign fishermen. The Act also created the North Pacific Fishery Management Council (NPFMC) as an advisory body to develop and implement management plans for Alaska groundfish.

As an interim step in the transition from foreign to domestic fishing, joint venture fisheries developed in the early 1980's in which U.S. fishing boats caught and delivered fish to foreign processing vessels (Megrey and Wespestad, 1990). Although joint venture catches were sizeable for some species, they were relatively modest for northern rockfish (Tables 1–3). By 1990, both the foreign and the joint venture fisheries for rockfish in Alaska had ended.

Domestic Fishery

Management History and Catch Statistics

Since passage of the MSFCMA, northern rockfish have been assigned to various management groupings (Table 4). Until the early 1990's, they were always managed as part of a "complex" or assemblage of rockfish species. Presumably, the original reason for this assemblage management was because it was thought to be too difficult for fisher-

Table 1.—Commercial catch of northern rockfish in the Gulf of Alaska, 1977–99.[1,2]

Year	Catch (t)			
	Foreign	Joint venture	Domestic	Total
1977	622	0	0	622
1978	553	0	0	553
1979	666	3	0	669
1980	809	Tr.[3]	0	809
1981	1,469	0	0	1,469
1982	3,914	0	0	3,914
1983	2,705	911	0	3,616
1984	489	492	N.a.[4]	N.a.
1985	Tr.	108	N.a.	N.a.
1986	Tr.	11	N.a.	N.a.
1987	0	51	N.a.	N.a.
1988	0	Tr.	N.a.	N.a.
1989	0	0	N.a.	N.a.
1990	0	0	1,697	1,697
1991	0	0	4,528	4,528
1992	0	0	7,770	7,770
1993	0	0	4,825	4,825
1994	0	0	5,968	5,968
1995	0	0	5,634	5,634
1996	0	0	3,386	3,386
1997	0	0	2,947	2,947
1998	0	0	3,051	3,051
1999	0	0	5,397	5,397

[1] Catches for 1977–92 are estimates based on extrapolation of catch composition data from the foreign and domestic observer programs.

[2] Data Sources:

1977: Wall, J., R. French, R. Nelson Jr., and D. Hennick. 1978. Data from the observations of foreign fishing fleets in the Gulf of Alaska, 1977. (Document submitted to the International North Pacific Fisheries Commission by the U.S. National Section.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1978: Wall, J., R. French, and R. Nelson Jr. 1979. Observations of foreign fishing fleets in the Gulf of Alaska, 1978. (Document submitted to the International North Pacific Fisheries Commission by the U.S. National Section.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1979: Wall, J., R. French, and R. Nelson Jr. 1980. Observations of foreign fishing fleets in the Gulf of Alaska, 1979. (Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Anchorage, Alaska, September 1980.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1980: Wall, J., R. French, and R. Nelson Jr. 1981. Observations of foreign fishing fleets in the Gulf of Alaska, 1980. (Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Vancouver, B. C., Canada, September 1981.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1981: Wall, J., R. Nelson Jr., and J. Berger. 1982. Observations of foreign fishing fleets in the Gulf of Alaska, 1981. (Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Vancouver, B. C., Canada, October 1982.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1982: Nelson, R., Jr., J. Wall, and J. Berger. 1983. Summary of U.S. observer sampling of foreign and joint-venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1982. (Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Anchorage, Alaska, October 1983.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1983: Berger, J., J. Wall, and R. Nelson Jr. 1984. Summary of U.S. observer sampling of foreign and joint-venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1983. (Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Vancouver, B.C., Canada, October 1984.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1984: Berger, J., J. Wall, and R. Nelson Jr. 1985. Summary of U.S. observer sampling of foreign and joint-venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1984. (Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Tokyo, Japan, October 1985.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, Building 4, 7600 Sand Point Way N. E., Seattle, WA 98115.

1985: Berger, J., J. Wall, and R. Nelson Jr. 1987. Summary of U.S. observer sampling of foreign and joint venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1985. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-112, 169 p.

1986: Berger, J., R. Nelson Jr., J. Wall, H. Weikart, and B. Maier. 1988. Summary of U.S. observer sampling of foreign and joint venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1986. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-128, 167 p.

1987: Berger, J., and H. Weikart. 1988. Summary of U.S. observer sampling of foreign and joint venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1987. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-148, 141 p.

1988: Berger, J., and H. Weikart. 1989. Summary of U.S. observer sampling of foreign and joint venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1988. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-172, 118 p.

1989: Heifetz, J., J. N. Ianelli, D. M. Clausen, and J. T. Fujioka. 1999. Slope rockfish. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 309–360. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

1990–91: Data on file at National Marine Fisheries Service, Alaska Region, P.O. Box 21668, Juneau, AK 99802 and Domestic Observer Program, National Marine Fisheries Service, Alaska Fisheries Science Center, REFM Division, 7600 Sand Point Way N. E., Seattle, WA 98115.

1992–98: Heifetz, J., J. N. Ianelli, D. M. Clausen, and J. T. Fujioka. 1999. Slope rockfish. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 309–360. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

1999: Data on file at National Marine Fisheries Service, Alaska Region, P.O. Box 21668, Juneau, AK 99802.

[3] Tr. = trace

[4] N.a. = not available

men to accurately identify the individual rockfish species, which are superficially similar in appearance. Also, many species were believed to sometimes co-occur in catches, which would make sorting to species a time consuming process.

Each year, the NPFMC assigned a single level of acceptable biological catch (ABC) and fishing quota (since 1988 the quota has been called "total allowable catch" (TAC)) for the entire complex or assemblage in each region.[6] Consequently, fishermen and processors were only required to report catches as "Pacific Ocean Perch Complex," "Slope Rockfish Assemblage," etc., without regard to which exact species in the assemblage they were actually taking. The assemblage approach as applied to northern rockfish management had a de facto ending in the Aleutian Islands in 1992, when the "Sharpchin/Northern" management subgroup was established in this region (Ito and Ianelli, 1994; sharpchin rockfish are so rare in the Aleutian Islands that the grouping is effectively northern rockfish alone). Likewise, northern rockfish were separated as a distinct management entity in the Gulf of Alaska in 1993 (Heifetz et al., 1993). In the eastern Bering Sea, however, northern rockfish in the years 1993–99 continued to be managed as part of the "Other Red Rockfish Assemblage" (Ito et al., 1999).

A completely domestic fishery for rockfishes, in which U.S. vessels both caught and processed the fish, began in the Gulf of Alaska and eastern Bering Sea in 1984, and in the Aleutian Islands in 1985 (Tables 1–3). Catches of northern rockfish in this fishery, however, cannot be determined for years before 1990. During these years, northern rockfish were part of either the Pacific Ocean Perch Complex or the Slope Rockfish Assemblage, so directly reported catch statistics for individual species are unavailable. This was not a problem in the foreign or joint venture fisheries because U.S. observers aboard foreign vessels collected species composition data that could be used to estimate the catch of northern rockfish. Unfortunately, a comparable observer program for domestic vessels was not implemented

Table 2.—Commercial catch of northern rockfish in the Aleutian Islands, 1977–99.[1,2]

	Catch (t)			
Year	Foreign	Joint venture	Domestic	Total
1977	5,311	0	0	5,311
1978	3,782	0	0	3,782
1979	997	0	0	997
1980	374	0	0	374
1981	138	2	0	140
1982	193	0	0	193
1983	28	Tr.[3]	0	28
1984	12	173	0	185
1985	Tr.	196	N.a.[4]	N.a.
1986	Tr.	200	N.a.	N.a.
1987	0	253	N.a.	N.a.
1988	0	441	N.a.	N.a.
1989	0	0	N.a.	N.a.
1990	0	0	1,273	1,273
1991	0	0	251	251
1992	0	0	1,041	1,041
1993	0	0	4,486	4,486
1994	0	0	4,667	4,667
1995	0	0	3,873	3,873
1996	0	0	6,708	6,708
1997	0	0	1,997	1,997
1998	0	0	3,675	3,675
1999	0	0	5,255	5,255

[1] Catches for 1977–91 are estimates based on extrapolation of catch composition data from the foreign and domestic observer programs. Catches for 1992–99 may include very small amounts of sharpchin rockfish.

[2] Data sources:

1977–86: Ito, D. H. 1988. Other rockfish. *In* R. G. Bakkala (Editor), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1987, p. 139–146. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-139.

1987–88: Berger and Weikart (1988, 1989; for references, see Table 1).

1989: Guttormsen, M., R. Narita, and J. Berger. 1990. Summary of U.S. observer sampling of foreign and joint venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1989. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-189, 84 p.

1990–91: Data on file at National Marine Fisheries Service, Alaska Region, P.O. Box 21668, Juneau, AK 99802 and Domestic Observer Program, National Marine Fisheries Service, Alaska Fisheries Science Center, REFM Division, 7600 Sand Point Way N. E., Seattle, WA 98115.

1992–99: Data on file at National Marine Fisheries Service, Alaska Region, P.O. Box 21668, Juneau, AK 99802.

[3] Tr. = trace

[4] N.a. = not available

[6] In actual practice, the ABC and quota for the Gulf of Alaska were further subdivided into three management areas: Western, Central, and Eastern.

Table 3.—Commercial catch of northern rockfish in the eastern Bering Sea, 1977–99.[1,2]

	Catch (t)			
Year	Foreign	Joint venture	Domestic	Total
1977	322	0	0	322
1978	119	0	0	119
1979	126	0	0	126
1980	58	11	0	69
1981	31	0	0	31
1982	68	2	0	70
1983	10	24	0	34
1984	19	13	N.a.[3]	N.a.
1985	5	2	N.a.	N.a.
1986	6	36	N.a.	N.a.
1987	2	51	N.a.	N.a.
1988	0	7	N.a.	N.a.
1989	0	12	N.a.	N.a.
1990	0	0	180	180
1991	0	0	623	623
1992	0	0	328	328
1993	0	0	959	959
1994	0	0	47	47
1995	0	0	287	287
1996	0	0	116	116
1997	0	0	118	118
1998	0	0	54	54
1999	0	0	145	145

[1] Catches for 1977–91 are estimates based on extrapolation of catch composition data from the foreign and domestic observer programs. Catches for 1992–99 may include very small amounts of sharpchin rockfish.

[2] Data sources:

1977–86: Ito (1988; see Table 2 for reference).

1987–88: Berger and Weikert (1988, 1989; see Table 1 for references).

1989: Guttormsen et al. (1990; see Table 2 for reference).

1990–91: Data on file at National Marine Fisheries Service, Alaska Region, P.O. Box 21668, Juneau, AK 99802 and Domestic Observer Program, National Marine Fisheries Service, Alaska Fisheries Science Center, REFM Division, 7600 Sand Point Way N. E., Seattle, WA 98115.

1992–99: Data on file at National Marine Fisheries Service, Alaska Region, P.O. Box 21668, Juneau, AK 99802.

[3] N.a. = not available

Table 4.—Management groupings[1] that northern rockfish were assigned to in the Gulf of Alaska, Aleutian Islands, and eastern Bering Sea, 1979–99.

Region and year	Management grouping
Gulf of Alaska	
1979–87	Pacific ocean perch complex
1988–90	Slope rockfish assemblage
1991–92	Other slope rockfish
1993–99	Northern rockfish
Aleutian Islands	
1979–90	Pacific ocean perch complex
1991–99	Sharpchin/northern
Eastern Bering Sea	
1979–90	Pacific ocean perch complex
1991–99	Other red rockfish

[1] Definition of management groupings:

Pacific ocean perch complex: Pacific ocean perch, *Sebastes alutus*; northern rockfish, *S. polyspinis*; rougheye rockfish, *S. aleutianus*; shortraker rockfish, *S. borealis*; and sharpchin rockfish, *S. zacentrus*.

Slope rockfish assemblage: The five species in the Pacific ocean perch complex, plus redstripe rockfish, *S. proriger*; harlequin rockfish, *S. variegatus*; silvergrey rockfish, *S. brevispinis*; and 13 minor species of *Sebastes*.

Other slope rockfish: Northern, sharpchin, redstripe, harlequin, and silvergrey rockfish and 13 minor *Sebastes* sp.

Northern rockfish: Northern rockfish only.

Sharpchin/northern: Sharpchin and northern rockfish.

Other red rockfish: Northern, rougheye, shortraker, and sharpchin rockfish.

until 1990, which left a gap in the catch estimates for the domestic fishery from 1984 to 1989. The domestic trawl fishery for rockfish developed rapidly over these years, especially in the Gulf of Alaska, where the reported catch of the Pacific ocean perch complex/slope rockfish assemblage increased from 119 metric tons (t) in 1984 to 19,002 t in 1989 (Heifetz et al., 1999). Presumably, some northern rockfish were taken, but most of the catch by the domestic fishery in this period is believed to be Pacific ocean perch, shortraker rockfish, *Sebastes borealis*; and rougheye rockfish, *Sebastes aleutianus*. These latter three species have traditionally been more valuable than northern rockfish on a price-per-pound basis, and there is evidence that some domestic fishermen were selectively harvesting them rather than northern rockfish (Heifetz and Clausen, 1990).

With the start of an observer program on U.S. groundfish vessels in 1990 (NPFMC, 1989a, 1989b), detailed information on domestic catches of rockfish in Alaska finally became available. In the Gulf of Alaska, catches of northern rockfish increased sharply from 1,697 t in 1990 to 7,770 t in 1992, and diminished somewhat in the years following (Table 1). This catch trend can be related to management actions of the NPFMC and NMFS during this period. In 1990, northern rockfish were in the Slope Rockfish Assemblage, along with Pacific ocean perch, shortraker and rougheye rockfish, and other species (Table 4). Fishermen were free to catch any of these species within the Slope Rockfish quota. Given the comparatively low market value of northern rockfish, fishing was apparently directed toward the three other species in the assemblage mentioned above. The result was a relatively moderate catch of northern rockfish that year. In 1991, however, the NPFMC separated Pacific ocean perch, shortraker rockfish, and rougheye rockfish from the rest of the Slope Rockfish Assemblage and assigned individual ABC's and TAC's for these three species (Heifetz and Clausen, 1992). These ABC's and TAC's were considerably less than the values in previous years, when a single ABC and TAC was set for all Slope Rockfish species combined. As a result of this more restrictive management policy, the rockfish fleet redirected more of its effort to northern rockfish, and catches for the species greatly increased in both 1991 and 1992. The high catches of northern rockfish in these two years raised concern among fishery assessment scientists that fishermen were selectively overharvesting this species within the "Other Slope Rockfish" management subgroup (Gulf of Alaska Groundfish Plan Team, 1992). Consequently, in 1993 the NPFMC implemented another change in rockfish management policy by separating out northern rockfish as its own distinct management subgroup in the Gulf of Alaska. The NPFMC assigned northern rockfish its own ABC and TAC, and since 1993, the restrictions imposed by this quota have resulted in the catches listed in Table 1. To ensure the TAC was not exceeded, and to limit bycatch of other species, catches in 1996–98 were further reduced due to in-season management actions by NMFS, which closed the fishery early.

In the Aleutian Islands, annual domestic catches of northern rockfish increased at a slower rate than those in the Gulf of Alaska (Table 2). Although northern rockfish in the Aleutian Islands were separated from the Pacific ocean perch complex in 1991 and assigned their own ABC and TAC, catches that year totaled only 251 t. A large increase in catches was finally seen in 1993, when nearly 4,500 t were taken, and catches have remained relatively large in the years thereafter. In 1994–96, catches were limited by mid-season closures for targeted fishing to ensure that the TAC was not exceeded. Since 1997, NMFS has prohibited targeted fishing for northern rockfish in the Aleutian Islands, and northern rockfish have been taken only as bycatch in other fisheries. This bycatch-only fishery was deemed necessary to prevent the closure of other more valuable fisheries in the Aleutian Islands, such as those for Atka mackerel and Pacific ocean perch (Smoker[7]). Such closures may have occurred if both targeted and bycatch fishing for northern rockfish were allowed and, in combination, were to cause the TAC for this species to be exceeded.

Annual domestic catches of northern rockfish in the eastern Bering Sea have consistently been much less than those in the Gulf of Alaska or Aleutian Islands (Table 3). Catches were highest in the years 1991–93, when targeted fishing was allowed during some periods. After 1993, catches for the "Other Red Rockfish" assemblage (of which northern rockfish was a member), were usually limited to bycatch only. TAC's for this assemblage were also quite small after 1993, which restricted the catches even further.

Targeted vs. Bycatch Fishing in the Gulf of Alaska and Aleutian Islands

Our analysis of the observer data indicates that in the Gulf of Alaska, the majority of northern rockfish catch has been taken by vessels specifically targeting this species, whereas in the Aleutian Islands it has been taken mostly as bycatch in other fisheries. As mentioned, management regulations since 1997 have limited the Aleutians fishery to bycatch only, but even before 1997, most of the catch was taken as bycatch. Because the observer database does not contain information on the intended target species for each haul, we used procedures described in Ackley and Heifetz (2001) to determine the probable target species. In these procedures, the predominant species by weight in a haul was usually determined to be the target. The results showed that for the overall period 1990–98, an estimated 81.8% of the northern rockfish catch in the Gulf of Alaska came from hauls that targeted this species, whereas only 20.6% of the northern rockfish catch in the Aleutian Islands came from targeted fishing (Table 5).

Most of this large bycatch of northern rockfish in the Aleutian Islands has been taken in the trawl fishery for Atka mackerel, *Pleurogrammus monopterygius*. For 1990–98, our targeting analysis indicated that 68.8% of the northern rockfish catch in the Aleutian Islands came from hauls that were actually targeting Atka mackerel (Table 6). Except for 1990, the

[7]Smoker, Andrew, Sustainable Fisheries Division, NOAA, Natl. Mar. Fish. Serv., Alaska Regional Office, Juneau, AK. Personal commun., April 2003.

Table 5.—Estimated percent of northern rockfish commercial catch in the Gulf of Alaska and Aleutian Islands that came from targeted fishing for northern rockfish, 1990–98, based on data in the National Marine Fisheries Service, Alaska Fisheries Science Center Observer Program database.

Year	Gulf of Alaska	Aleutian Islands
1990	47.1	26.2
1991	91.3	20.0
1992	82.8	5.9
1993	81.3	13.2
1994	92.3	15.3
1995	89.9	22.3
1996	74.1	35.3
1997	68.8	11.5
1998	53.8	18.9
All years comb.	81.8	20.6

Table 6.—Estimated percent of northern rockfish commercial catch in the Aleutian Islands taken as bycatch in the Atka mackerel targeted fishery, 1990–98, based on data in the National Marine Fisheries Service, Alaska Fisheries Science Center Observer Program database.

Year	Percent
1990	31.0
1991	66.4
1992	75.9
1993	78.2
1994	75.8
1995	68.4
1996	57.7
1997	79.7
1998	71.7
All years comb.	68.8

Table 7.—Summary of information on the commercial fishery for northern rockfish in the Gulf of Alaska and Aleutian Islands, 1990–99.[1]

Region and year	Catch (t)	ABC[2] (t)	TAC[2] (t)	% discarded	% caught by factory trawlers	% caught by shore-based trawlers	No. vessels in fishery[3]	Mean duration of tow (min)[4]
Gulf of Alaska								
1990	1,697			N.a.[5]	N.a.	N.a.	12	124
1991	4,528			N.a.	N.a.	N.a.	21	68
1992	7,770			N.a.	N.a.	N.a.	28	119
1993	4,825	5,760	5,760	26.5	99.2	0.8	21	151
1994	5,968	5,760	5,760	17.7	93.8	6.2	21	116
1995	5,634	5,270	5,270	12.7	91.4	8.6	24	127
1996	3,343	5,270	5,270	16.5	69.2	30.8	30	113
1997	2,947	5,000	5,000	28.0	68.9	31.1	22	156
1998	3,051	5,000	5,000	18.3	46.9	53.1	22	94
1999	5,397	4,990	4,990	11.1	60.2	39.8	N.a.	N.a.
Aleutian Islands								
1990	1,273			N.a.	N.a.	N.a.	10	171
1991	251	3,440	3,440	N.a.	N.a.	N.a.	2	60
1992	1,041	5,670	5,670	N.a.	N.a.	N.a.	11	94
1993	4,486	5,670	5,100	92.9	100.0	0.0	17	124
1994	4,667	5,670	5,670	82.9	100.0	Tr.[6]	11	129
1995	3,873	5,670	5,103	68.8	100.0	0.0	14	82
1996	6,708	5,810	5,229	64.5	100.0	0.0	11	109
1997	1,997	4,360	4,360	92.7	100.0	0.0	4	144
1998	3,675	4,230	4,230	89.5	100.0	Tr.	8	164
1999	5,255	4,230	4,230	90.1	100.0	Tr.	N.a.	N.a.

[1] Data sources: For catch, percent discarded, percent caught by factory trawlers, and percent caught by shore-based trawlers: National Marine Fisheries Service, Alaska Region, P. O. Box 21688, Juneau, AK 99802-1668. For ABC and TAC: North Pacific Fishery Management Council, 605 W. 4th. Avenue, Suite 306, Anchorage, AK 99501-2252. For number of vessels in fishery and mean duration of tow: Observer Program database, National Marine Fisheries Service, Alaska Fisheries Science Center, REFM Division, 7600 Sand Point Way N. E., Seattle, WA 98115.

[2] Acceptable biological catch (ABC) and total allowable catch (TAC) are not listed for 1990–92 in the Gulf of Alaska and for 1990 in the Aleutian Islands because northern rockfish were not in their own management category these years.

[3] Number of vessels that had at least one haul in the observer database for which northern rockfish was determined to be the target species.

[4] Time between brake-set and haulback (generally equivalent to time on bottom) for hauls in which northern rockfish was determined to be the target species.

[5] N.a. = data not available.

[6] Tr. = trace.

majority of the northern rockfish catch in the Aleutians has consistently been taken as bycatch in the Atka mackerel targeted fishery. In reality, the actual percentage of northern rockfish caught in the Atka mackerel fishery was likely even higher than the data in Table 6 indicate. For example, there were many incidences in the observer database where a vessel made a series of hauls in the same general location, and all but one or two caught predominantly Atka mackerel. In these exceptions, northern rockfish often comprised a dominant percentage of the catch, and in our targeting analysis, these hauls were identified as targeting northern rockfish. In such cases, however, the vessel was more likely directing its efforts toward Atka mackerel, but had unintentionally encountered a large catch of northern rockfish.

Because of the bycatch nature of the northern rockfish catch in the Aleutian Islands, the reader is cautioned that much of the information in this report from commercial fishery data in the Aleutian Islands may be somewhat biased in regards to northern rockfish. The fishery data may be more an indication of how the Atka mackerel fishery operates rather than what a true directed fishery for northern rockfish would show.

Description of the Fishery in the Gulf of Alaska and Aleutian Islands

The domestic rockfish fishery in Alaska was pioneered by factory-trawler vessels that catch and process fish at sea, and these catcher-processors have generally dominated the northern rockfish fishery in the Gulf of Alaska (Table 7). The majority of these vessels are about 150–250 ft in length, and carry a crew of about 30–40, including processors.[8]

[8]This description of the factory-trawler fishery was based on interviews in August 1997 with the following individuals: Andrew Smoker, Sustainable Fisheries Division, NOAA, Natl. Mar. Fish. Serv., Alaska Regional Office, Juneau, AK; Eric Hollis, Fishing Company of Alaska, Seattle, WA; Laurie Bowen, Tyson Seafood, Seattle, WA; and Tim Meintz, Cascade Fishing, Seattle, WA.

Northern rockfish in the Gulf of Alaska are generally caught with bottom trawls identical to those used in the Pacific ocean perch fishery. Many of these nets are equipped with so-called "tire gear," in which automobile tires are attached to the footrope of the net to facilitate towing over rough substrates. The fish are headed, gutted, and frozen on board, and then exported to markets in Asia, primarily Japan and South Korea. The Japanese market, in particular, esteems fish that are red in color; because northern rockfish tend to have less red coloration than Pacific ocean perch, they are correspondingly lower in value and are generally marketed as a low-cost substitute for Pacific ocean perch.

Northern rockfish have also been caught by shore-based trawlers in the Gulf of Alaska since 1993 (Table 7). This fishery remained relatively small until 1996, when it expanded substantially and took nearly 31% of the Gulfwide catch. The shore-based vessels are much

smaller than the factory-trawlers and range in length from about 70–120 ft; crew size is roughly 3–5 (Blackburn[9]). The fish are caught and retained on board in tanks of refrigerated seawater for as long as 3 days, after which they are delivered to shore-side plants in the port of Kodiak for processing and freezing. Because of the economic advantages of operating close to port, virtually all the shore-based catches have come from waters around Kodiak Island.

The annual number of vessels in the Gulf of Alaska that our analysis determined to have targeted northern rockfish has ranged from 12 to 30 (Table 7). The actual number of vessels in the fishery after 1995 is probably underestimated in Table 7, however, because the smaller shore-based vessels that entered the fishery during these years had a lower level of observer coverage than the larger factory trawlers.[10] Consequently, some of these smaller vessels likely were not listed in the observer database each year. Mean duration of an individual tow in the Gulf of Alaska that targeted northern rockfish has usually been about 2 hours on bottom (Table 7). Duration of individual tows, however, has been quite variable, and has ranged from 2 to 570 min.

In the Aleutian Islands, the number of vessels determined to be targeting northern rockfish has been fewer than in the Gulf of Alaska, and has ranged from 2 to 17 in the years 1990–98 (Table 7). As discussed, some of these vessels in reality may have been attempting to catch Atka mackerel rather than northern rockfish. The lower number of vessels in the Aleutian Islands is due in part to the near absence of any shore-based fishing in this region. Most of the vessels in the Atka mackerel fishery have a history of also participating in Gulf of Alaska and Aleutian Islands rockfish fisheries, so the previous description of rockfish factory-trawlers applies equally to these vessels.

[9]Blackburn, Chris, Alaska Groundfish Data Bank, Kodiak, AK. Personal commun., May 1997.

[10]NPFMC regulations require only 30% of the vessels less than 125 ft to have an observer on board, whereas all vessels over 125 ft must have an observer.

Discard Rates for Northern Rockfish

The amount of the northern rockfish catch discarded and not retained for processing has differed markedly between the Gulf of Alaska and Aleutian Islands (Table 7). In the Gulf of Alaska, annual discard rates have been relatively low, ranging from 26.5% in 1993 to only 11.1% in 1999. In contrast, annual discards of northern rockfish in the Aleutian Islands have been consistently very high, with several years showing discard rates of around 90%. This difference can be explained by a combination of two factors: 1) because northern rockfish in the Aleutian Islands are mostly caught as bycatch in the Atka mackerel fishery, catcher-processors in this fishery are not set up for processing northern rockfish, and 2) northern rockfish in the Aleutian Islands appear to be much smaller in size than those in the Gulf of Alaska (data supporting this observation are presented later in this report). These small fish are of lower market value; consequently, there is less economic incentive for fishermen to retain them.

Seasonality of Fishery

The distribution of the northern rockfish catch by month for both the Gulf of Alaska and Aleutian Islands is shown in Figure 2 for the years 1990–98 combined. The seasonal distribution of catches has been very different in each region. In the Gulf of Alaska, the majority of the catch has been taken in July, with a secondary peak in October. In the Aleutian Islands, however, most of the catch has come in the spring, although sizeable catches are also seen in other months. These seasonal catch patterns are largely determined by fishery opening and closing regulations enacted by NMFS. In the Gulf of Alaska, the directed rockfish trawl fishery during these years has traditionally opened on 1 July, which accounts for the large catches during this month. Rockfish trawlers usually direct their efforts first toward Pacific ocean perch because of its higher value relative to other rockfish species; after the TAC for Pacific ocean perch has been reached and NMFS closes directed fishing for this species, trawlers then switch and target northern rockfish. In some years, the northern rockfish fishery extended into August until it was closed, which explains the catches seen for this month in Figure 2. In other instances, directed fishing was closed in July or August before the TAC was achieved. The rockfish trawl fishery was then opened again in October to allow the remainder of the quota to be filled, which accounts for the relatively large catches seen in this month. In the Aleutian Islands, the monthly distribution of northern rockfish catches is chiefly related to the timing of the Atka mackerel fishery, in which the majority of northern rockfish are caught. Due to NMFS regulations, the Atka mackerel fishery in recent years has mostly occurred in the spring, resulting in a large bycatch of northern rockfish during March, April, and May.

This seasonal pattern of the fishery, especially in the Gulf of Alaska, needs to be kept in mind when considering some of the results presented in this paper. For example, examination of the depth distribution of northern rockfish in the Gulf based on fishery data will emphasize the summer distribution of the fish because this is when most of the data have been collected.

Catch by Gear Type and On-bottom vs. Off-bottom Catches

According to the observer database, bottom trawls have accounted for over 99% of the northern rockfish catch in both the Gulf of Alaska and Aleutian Islands (Table 8). A very small amount has been taken by pelagic trawls. Bottom trawls can be defined as nets specifically designed to handle the rigors of towing over the bottom, with weighty "doors" to sink and spread the net, and heavy footropes and webbing. In contrast, pelagic trawls are designed for off-bottom towing with lighter doors, footropes, and webbing, and they usually have a much larger vertical and horizontal spread at the mouth for capturing pelagic schools of fish. It should be noted, however, that bottom trawls are sometimes fished off bottom; likewise, skilled fishermen can fish pelagic trawls very near or just touching the bottom, especially where the substrate is smooth.

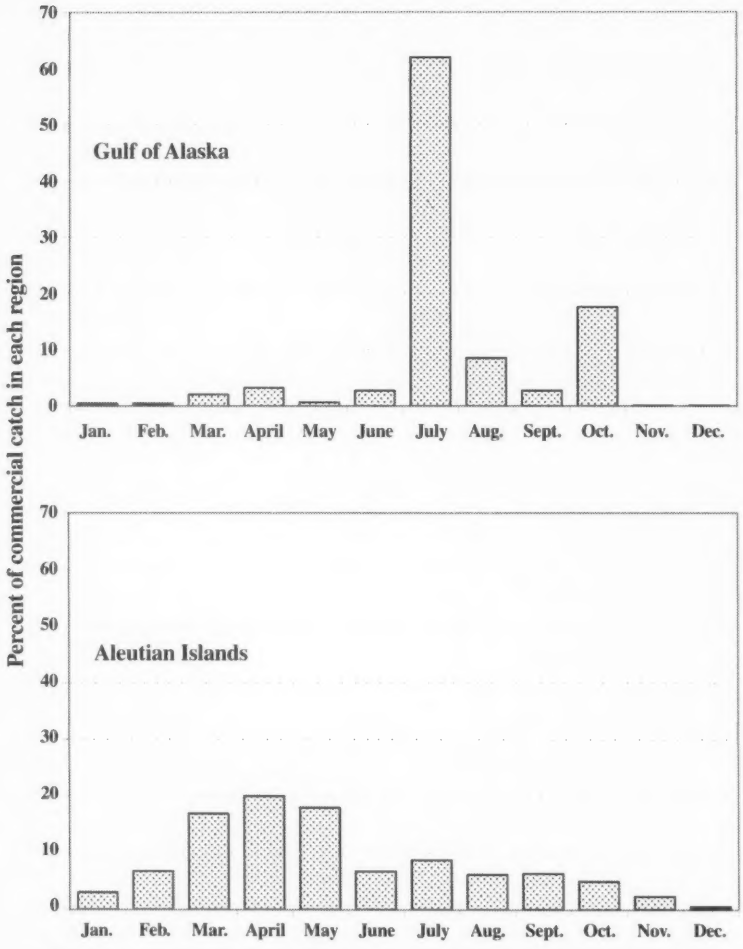

Figure 2.—Distribution by month of the northern rockfish commercial catch in the Gulf of Alaska and Aleutian Islands, 1990–98, based on data collected by the NMFS Alaska Fisheries Science Center Observer Program.

Catches of northern rockfish in pots or on longlines have been very low (Table 8). Although in the Aleutian Islands this species has been taken relatively often on longlines (over 3,400 observed longline hauls have shown catches of northern rockfish), longline catches amount to only 0.5% of the total for this region. In the Gulf of Alaska, catches of these fish on longlines are much less frequent, and longlines account for only a trace of the region's total catch of this species. These low catches in pots or on longlines can be explained by the diet preferences of northern rockfish. Food studies of northern rockfish in both the Gulf of Alaska and Aleutian Islands indicate that the fish feed predominantly on plankton, especially euphausiids and copepods (Yang, 1993; 1996). Therefore, it is likely that northern rockfish are not attracted to baited gear such as pots or longlines.

In the eastern Bering Sea, bottom trawls have also been the predominant gear for catching northern rockfish, with an estimated 92% of the catch coming from bottom trawls. Compared to the Gulf of Alaska and Aleutian Islands, however, the frequency and percentage of catches of northern rockfish in the eastern Bering Sea coming from pelagic trawls has been much higher. This can be explained by the large amount of pelagic trawling for walleye pollock in the Bering Sea in which small amounts of northern rockfish may be taken as bycatch.

In both the Gulf of Alaska and Aleutian Islands, about 90% of the northern rockfish catch has been taken on bottom (Fig. 3). Furthermore, for the portion of the catch taken off bottom, there appears to be a trend toward larger catches as hauls are made increasingly close to bottom. For example, in the Gulf of Alaska, most (71%) of the off-bottom catch has been taken within the first 10 m of the bottom. These data suggest that adult northern rockfish are mostly demersal in nature, and that there may be little pelagic component to their distribution, at least during those times of the year when the commercial fishery has operated. Also, it should be noted that some of the vessels that fish for northern rockfish in the Gulf of Alaska have successfully used pelagic trawls for capturing off-bottom aggregations of rockfish, in particular Pacific ocean perch. The fact that they have not chosen to do this for northern rockfish is a further indication that northern rockfish are mostly bottom-oriented in their distribution.

Depth Distribution of the Catch

Observer data were analyzed to determine the depth distribution of commercial hauls that caught northern rockfish in the Gulf of Alaska and Aleutian Islands. Results showed most of the northern rockfish catch in both regions was taken from a relatively narrow depth range (Fig. 4). In the Gulf of Alaska, about 70% of the catch came from depths between 75 and 125 m, with the 75–100 m stratum showing the highest catches. In the Aleutian Islands, catches were distributed slightly deeper, with about 65% taken at depths 100–150 m, and the 100–125 stratum showing the highest catches. In both regions, the depth distribution was not symmetrical; catches abruptly dropped to near zero at depths less than 50 m, but gradually tapered off at depths

greater than 150–175 m. Even at depths exceeding 300 m, several hauls reported catches of northern rockfish in excess of 5–10 t. In the Gulf of Alaska, the deepest haul with a substantial catch of northern rockfish (>10 t) was at 387 m and in the Aleutian Islands at 604 m.

Location of Fishing Grounds

To determine the geographic distribution of northern rockfish catches in the commercial fishery, we examined data from the observer program for the years 1990–98. Geographic information system (GIS) plots of all hauls that contained any northern rockfish show that catches have been widespread along the outer continental shelf and upper continental slope in the Gulf of Alaska, Aleutian Islands, and eastern Bering Sea (Fig. 5A, 6A, 7A). The Gulf of Alaska catches become relatively infrequent in the eastern Gulf, and southeastern Alaska is not included in Figure 5A because only a few hauls caught northern rockfish in this area.

To further examine the geographic distribution of catches, we arbitrarily selected only those hauls in the upper 20% of all northern rockfish catches, and we also plotted these catches (Fig. 5B, 6B, 7B). In the Gulf of Alaska, hauls in this upper 20% quantile (equivalent to a northern rockfish catch of ≥3,500 kg) comprised 86.3% of the total catch of this species in this region for the years 1990–98. Similarly, in the Aleutian Islands, the upper 20% quantile (equivalent to a northern rockfish catch ≥1,631 kg) amounted to 82.0% of the northern rockfish catch. Because of the much smaller catches of northern rockfish in the eastern Bering Sea, the upper 20% quantile level for the Aleutian Islands was used to make the plot for the eastern Bering Sea (Fig. 7B) comparable to that for the Aleutian Islands. This level (≥1,631 kg) comprised 72.6% of the total catch of northern rockfish in this region for the years 1990–98.

Thus, Figures 5B–7B show that the highest individual catches, and the bulk of the northern rockfish total catch, are concentrated at a number of discrete fishing grounds that are relatively small in size. Outside these grounds, northern rockfish are still often encountered

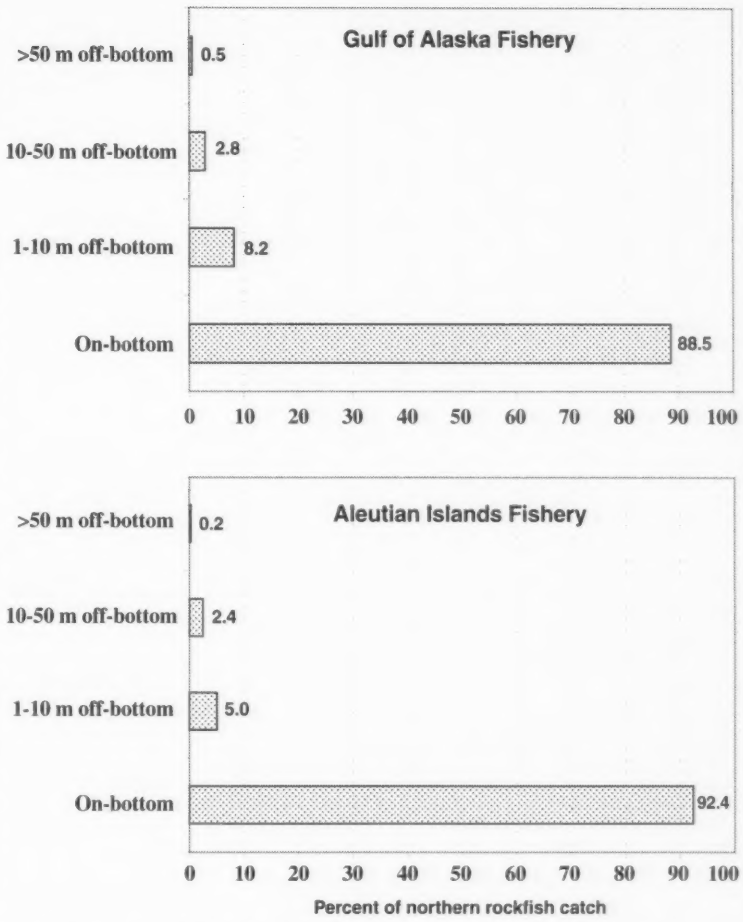

Figure 3.—On-bottom vs. off-bottom distribution of catches of northern rockfish in the Gulf of Alaska and Aleutian Islands commercial fisheries, 1990–98, based on data collected by the NMFS Alaska Fisheries Science Center Observer Program.

Table 8.—Summary by region and gear type of northern rockfish (NR) commercial catches, 1990–98, based on data in the National Marine Fisheries Service, Alaska Fisheries Science Center Observer Program database.

Region and gear type	No. of observed hauls with NR catch	% of NR catch in region	Mean NR catch/haul (kg)	Maximum NR catch per haul (kg)
Gulf of Alaska				
bottom trawl	7,990	99.9	2,845.2	77,155.3
pelagic trawl	416	0.1	62.5	5,327.1
pot	39	Tr.[1]	2.8	19.0
longline	184	Tr.	10.4	75.0
Aleutian Islands				
bottom trawl	11,074	99.4	1,766.9	55,631.8
pelagic trawl	126	0.1	113.1	6,865.1
pot	157	Tr.	2.6	42.8
longline	3,459	0.5	30.3	747.6
Eastern Bering Sea				
bottom trawl	1,875	92.4	752.8	60,301.2
pelagic trawl	3,842	6.3	24.9	9,720.6
pot	429	0.1	3.6	75.8
longline	1,113	1.2	16.5	439.1

[1] Tr. = trace

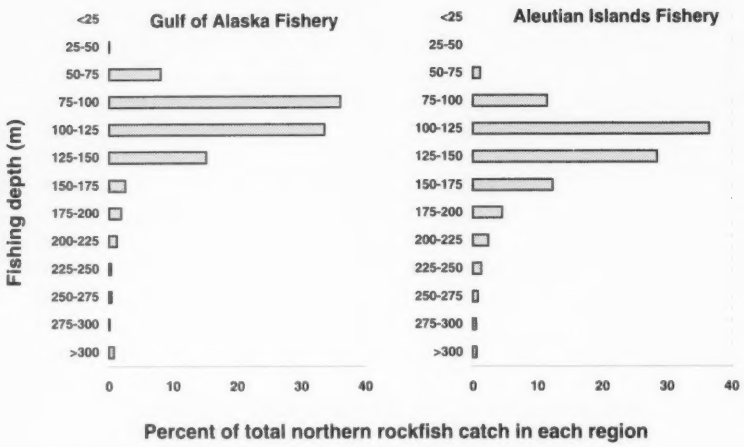

Figure 4.—Depth distribution of the catch of northern rockfish in the Gulf of Alaska and Aleutian Islands commercial fisheries, 1990–98, based on data collected by the NMFS Alaska Fisheries Science Center Observer Program.

Table 9.—Major commercial fishing grounds for northern rockfish in the Gulf of Alaska, Aleutian Islands, and eastern Bering Sea, 1990–98, based on data in the National Marine Fisheries Service, Alaska Fisheries Science Center Observer Program database. Data are for hauls using bottom trawls only and do not include hauls that did not catch northern rockfish.

Region and fishing ground	No. of hauls with NR[1] catch	% of NR catch in region	Mean NR CPUE[2] (kg/hr)	Mean depth of hauls (m)
Gulf of Alaska				
Portlock Bank	1,397	19.4	1,931.4	147
Albatross Bank	748	11.2	2,511.8	134
Snakehead	944	45.8	11,737.6	130
Shumagin Bank	668	7.9	2,194.4	90
Davidson Bank	319	4.4	1,873.5	128
All Gulf of Alaska	7,990	100.0	2,391.3	140
Aleutian Islands				
Seguam Pass	2,244	9.0	392.1	154
N & S of Amlia I.	591	4.2	599.0	158
Delarof I.	487	3.1	645.4	146
Petrel Bank	1,122	17.8	1,453.4	129
S of Amchitka I.	495	6.7	1,565.5	158
SW of Amchitka I.	491	3.6	1,000.7	151
Sturdevant Rock	1,625	19.5	1,202.4	103
Buldir Reef	560	6.6	1,050.7	133
W of Buldir I.	489	5.6	1,588.5	135
Tahoma Reef	252	4.5	1,893.1	190
Ingenstrem Rocks	69	3.3	3,350.2	117
All Aleutians	11,074	100.0	946.0	144
Eastern Bering Sea				
SE Zhemchug Canyon	353	61.7[3]	969.2	140
All Eastern Bering Sea	1,875	100.0	329.1	147

[1] NR = northern rockfish
[2] CPUE = catch per unit effort
[3] 57.0% of northern rockfish catch for all gear types in the eastern Bering Sea

(Fig. 5A–7A), but generally in sparse quantities.

In the Gulf of Alaska, there appear to be five major fishing grounds: Portlock Bank, Albatross Bank, an unnamed bank south of Kodiak Island that fishermen commonly refer to as the "Snakehead," Shumagin Bank, and Davidson Bank (Fig. 5B; Table 9). Cumulatively, commercial hauls from these five banks have yielded an estimated 88.7% of the total northern rockfish catch in the Gulf of Alaska. The Snakehead appears to be a particularly productive locality for northern rockfish; it accounted for nearly 46% of the Gulf of Alaska catch of northern rockfish in 1990–98, and had a much higher catch per unit effort (CPUE) than any of the other major fishing grounds.

These fishing grounds share some geographic and physical characteristics, which may be an indication of the preferred habitat for adult northern rockfish. All five banks appear to consist of relatively shallow, isolated rises or banks located on the outer continental shelf near the beginning of the upper continental slope (i.e. the 200 m depth contour). Mean depth of hauls made on the grounds ranges from 90 to 147 m (Table 9), which is shallower than what would be expected given their offshore location, and each is separated from land by an intervening stretch of deeper water.

A comparison of the depth distribution of the commercial catch (Fig. 4) with the mean depth of the fishing grounds (Table 9) shows that the commercial catch is distributed somewhat shallower than the mean depth of the fishing grounds. This indicates the shallower portions of the grounds account for a greater percentage of the catch.

In the Aleutian Islands, there are at least 11 identifiable major fishing grounds for northern rockfish (Fig. 6B; Table 9). This number is greater than the five major grounds identified in the Gulf of Alaska, and it may reflect the more complicated offshore topography of the Aleutian Islands, with their numerous passes between the Bering Sea and the North Pacific Ocean and many offshore reefs. Also, establishment of trawl exclusion zones in the Aleutian Islands in 1991 to protect Steller sea lions[11] (in which trawling was prohibited within 10 n.mi. of sea lion rookeries) may have caused the artificial separation of some of the grounds. For example, trawl exclusion zones lie between the Buldir Reef and west of Buldir Islands grounds and between the grounds south and southwest of Amchitka Island. If the trawl exclusion

[11] Steller Sea Lion Protection Measures Final Supplemental Environmental Impact Statement, Nov. 2001. Avail. from Natl. Mar. Fish. Serv., Alaska Region, P.O. Box 21668, Juneau, AK 99802-1668.

zone did not exist in the Buldir area, fishing might extend continuously between the two fishing grounds that are now found at this locality, and the same might also be true for the Amchitka area.

The 11 grounds identified in Figure 6B and Table 9 cumulatively account for 83.9% of the northern rockfish catch in the Aleutian Islands for the years 1990–98. The ground providing the highest percentage of northern rockfish catch is Sturdevant Rock, with 19.5% of the Aleutian Islands total. Other important grounds are Petrel Bank and Seguam Pass. The highest CPUE was at Ingenstrem Rocks, although this may be due to the relatively small effort (only 69 hauls in which northern rockfish were caught) at this locality.

Except for Amlia Island, all the fishing grounds for northern rockfish in the Aleutian Islands are also important fishing areas for Atka mackerel (Fritz[12]), which would be expected given that most northern rockfish in this region are taken as bycatch in the Atka mackerel fishery. Seguam Pass in particular appears to be an important fishing ground for northern rockfish not because of a high abundance of the species at this locality, but due to the intensive fishing effort for Atka mackerel that occurs there. This is shown by the data in Table 9, in which Seguam Pass had the third highest catch of northern rockfish in the Aleutian Islands and also the highest number of hauls, but had a CPUE much lower than any of the other grounds.

Similar to the Gulf of Alaska, several of the fishing grounds in the Aleutian Islands may be characterized as offshore banks or rises of relatively shallow depth, which are surrounded by deeper water on all sides. This appears to be the case particularly for Seguam Pass, Petrel Bank, and Tahoma Reef. Other fishing grounds, however, such as those off Amlia and Amchitka Islands, are located relatively close to shore where the shelf follows the more typical pattern

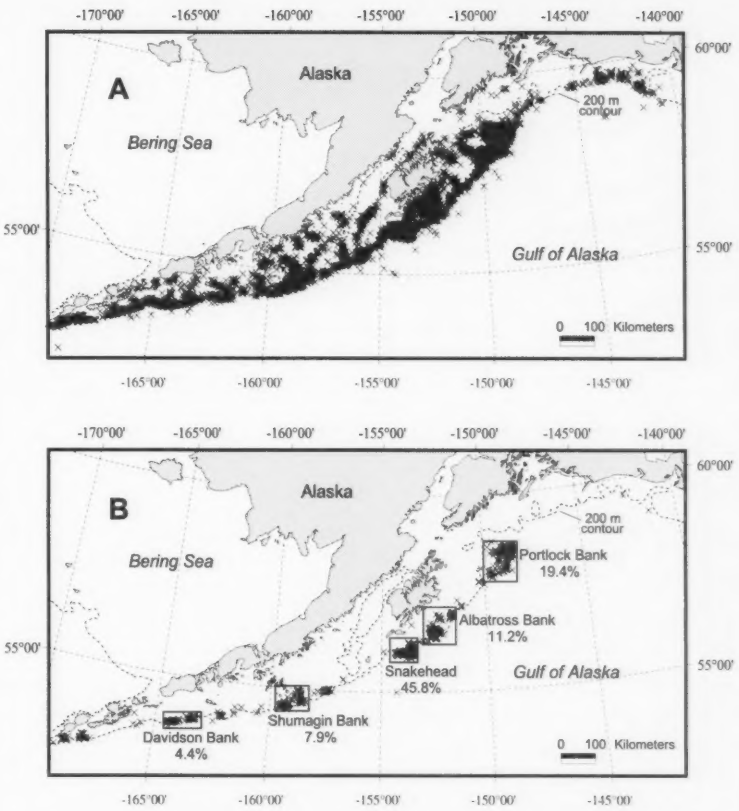

Figure 5.—Location of hauls that caught northern rockfish in the Gulf of Alaska commercial fishery, 1990–98, based on data collected by the NMFS Alaska Fisheries Science Center Observer Program. A: All hauls that caught northern rockfish; B: Hauls in the upper 20% quantile of northern rockfish catches (= catch of northern rockfish ≥3.5 t). Also shown in B are the major commercial fishing grounds for northern rockfish in the Gulf of Alaska that were identified in this study, along with each ground's estimated percent by weight of the Gulfwide commercial catch of northern rockfish for the years 1990–98.

of sloping gradually into deeper water. Mean depth of the 11 fishing grounds ranges from 103 to 190 m (Table 9). Also similar to the Gulf of Alaska, a comparison of the depth distribution of the catch with the mean depth of the fishing grounds (Fig. 4 vs. Table 9) indicates that highest catches come from shallower portions of the grounds.

In the eastern Bering Sea, only one major fishing ground was evident (Fig. 7B.). In Figure 7B, we call this ground "Southeast Zhemchug Canyon," although it is actually located adjacent to rather than in the canyon. This fishing ground accounted for nearly 62% of all the northern rockfish catch taken by bottom trawls in this region (57% of the catch for all gear types (Table 9)). Comparing Figure 7A with Figure 7B shows that northern rockfish have been caught in very sparse amounts at many locations in the eastern Bering Sea, with Southeast Zhemchug Canyon the only significant locality where large catches were taken. The Southeast Zhemchug Canyon fishing ground can be physically characterized as a shallow offshore rise on the outer continental shelf, surrounded by deeper water, so it is similar topographically to

[12]Fritz, Lowell, NOAA, Natl. Mar. Fish. Serv., Alaska Fisheries Science Center, Resource Ecology and Fish Management Division, Bldg. 4, 7600 Sand Point Way N.E., Seattle, WA 98115. Unpubl. data, May 2000.

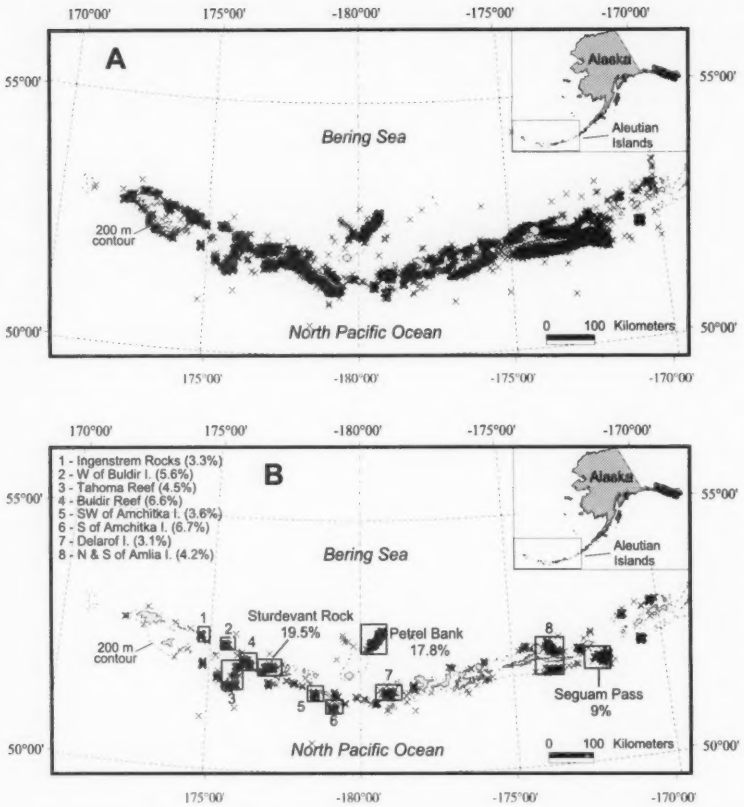

Figure 6.—Location of hauls that caught northern rockfish in the Aleutian Islands commercial fishery, 1990–98, based on data collected by the NMFS Alaska Fisheries Science Center Observer Program. A: All hauls that caught northern rockfish; B: Hauls in the upper 20% quantile of northern rockfish catches (= catch of northern rockfish ≥1.631 t). Also shown in B are the major commercial fishing grounds for northern rockfish in the Aleutian Islands that were identified in this study, along with each ground's estimated percent by weight of the region's commercial catch of northern rockfish for the years 1990–98.

many of the other fishing grounds for northern rockfish.

Size of Fish Caught in the Fishery

Mean size of northern rockfish taken by the commercial fishery was significantly larger in the Gulf of Alaska compared to the Aleutian Islands. We used observer data for the years 1990–98 on the estimated total weight and numbers of northern rockfish in each haul to compute mean weight per fish. For each year, mean weight per fish was consistently greater in the Gulf of Alaska than in the Aleutian Islands (Fig. 8). Overall mean weight per fish during the entire period was 0.68 kg in the Gulf of Alaska and only 0.53 kg in the Aleutian Islands.

Data in the eastern Bering Sea were too sparse to compute mean weight per fish on an annual basis, but estimated mean weight for the years 1990–98 combined was 0.50 kg. Thus, size of northern rockfish caught in the eastern Bering Sea was similar to that of the Aleutian Islands.

Length frequency data for northern rockfish were collected by observers on a consistent basis only in the Gulf of Alaska. Generally, lengths were taken only from hauls with a large catch of

Table 10.—Sex composition of northern rockfish sampled by observers in the Gulf of Alaska commercial fishery, 1990–98.

Year	% male	% female	No. sexed
1990	52.4	47.6	2,786
1991	48.9	51.1	5,867
1992	44.2	55.8	10,628
1993	44.7	55.3	8,182
1994	46.4	53.6	6,696
1995	50.7	49.3	6,633
1996	51.0	49.0	5,049
1997	50.8	49.2	3,683
1998	47.9	52.1	5,787
Total	47.7	52.3	55,311

northern rockfish where this species predominated in the catch. Most fish were between 30 and 42 cm fork length, and mean fork length was 36.1 cm (Fig. 9).

Sex was also determined for many of the northern rockfish sampled by observers for length in the Gulf of Alaska. Females had a mean fork length that was almost 1 cm longer than that for males (Fig. 10). A *t*-test of the difference between two means indicated that this difference was highly significant ($P < 0.0001$, $t = 38.57$, df = 55,309), which was not surprising given the large sample size that was taken.

Sex Ratio of Fish Caught in the Gulf of Alaska Fishery

Northern rockfish sex ratios determined from the observer data in the Gulf of Alaska were often close to 50:50 on an annual basis, but pooling these data over all years showed females predominated by a ratio of 52.3:47.7 (Table 10). This pooled ratio may have been affected by the fact that the 2 years with the highest percentage of females (1992 and 1993) also were the years in which the most number of fish were sexed.

To determine whether the sex ratio for all years combined differed significantly from 50:50, we conducted replicated tests of goodness of fit as described in Sokal and Rohlf (1969). In this procedure, each haul is treated as a replicate, and a chi-square test is then performed for each haul, which allows a pooled chi-square statistic to be computed for all the data combined. Our computed statistic for the pooled data was highly significant (chi-square = 119.9; df = 1; $P < 0.0001$; therefore, we reject the null hypothesis

of a 50:50 sex ratio and conclude there were significantly more females caught in the Gulf of Alaska fishery.

We further examined the sex composition of northern rockfish in individual hauls to see if the fish were aggregated by sex on a localized basis. For this, we selected only those hauls in which sex was determined for ≥40 northern rockfish. About two-thirds of the hauls were within 10% of a 50:50 sex ratio, but there were also many hauls in which either sex considerably predominated (Fig. 11). To determine whether the sex ratios in individual hauls differed significantly from 50:50, we again used replicated tests of goodness of fit similar to those described above. If each haul that had ≥40 sexed fish is treated as a replicate, and a chi-square test is performed for each haul, then a chi-square statistic can be computed among replicates to measure the significance of heterogeneity among hauls (Sokal and Rohlf, 1969). Our computed statistic was highly significant (chi-square = 2,453; df = 549; P <0.0001), which indicated that individual hauls were very heterogeneous and differed greatly from a 50:50 ratio. It should be noted, however, that the chi-square tests for individual hauls showed that in the majority of hauls (67.7%) the sex ratio was not significantly different than 50:50. Therefore, at most localities, the sex ratio could be characterized as uniform, but locations with a skewed sex ratio were sufficiently common to cause the replicated tests of goodness of fit to indicate a high degree of heterogeneity among hauls.

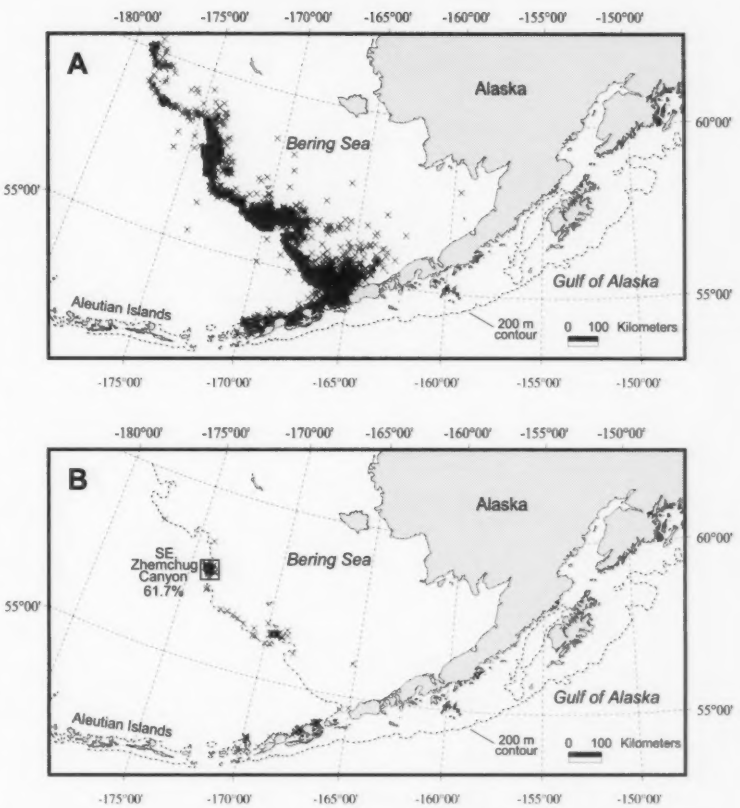

Figure 7.—Location of hauls that caught northern rockfish in the eastern Bering Sea commercial fishery, 1990–98, based on data collected by the NMFS Alaska Fisheries Science Center Observer Program. A: All hauls that caught northern rockfish; B: Hauls with a catch of northern rockfish ≥1.631 t. Also shown in B is the major commercial fishing ground for northern rockfish in the eastern Bering Sea that was identified in this study, along with the ground's estimated percent by weight of the region's commercial bottom trawl catch of northern rockfish for the years 1990–98.

CPUE in the Gulf of Alaska Fishery

We examined CPUE in the commercial fishery for northern rockfish in the Gulf of Alaska for the years 1990–98. In this analysis, CPUE (kilograms of northern rockfish caught per hour trawled) was calculated for each haul in the observer database that we had previously determined to be targeted on northern rockfish. The average of these values for each year was then computed to yield overall mean CPUE's. It is well known that commercial fishery CPUE data may be biased when used as an indicator of trends in stock abundance, especially when dealing with an aggregated species such as northern rockfish (Quinn and Deriso, 1999). Rather than determining abundance trends, the purpose of this analysis was to document the typical CPUE in the fishery, and to see if any gross temporal changes in CPUE were apparent.

Results showed mean annual CPUE was generally in the range of 5,000–9,000 kg/h (Table 11). The one exception was 1991, when mean CPUE was almost 18,000 kg/h. The high CPUE in 1991 appeared to be caused by one highly productive vessel that dominated the fishery that year in terms of hauls targeted on northern rockfish.

Table 11.—Mean CPUE (kg/h trawled) of northern rockfish (NR) in the Gulf of Alaska commercial fishery, 1990–98, based on hauls in the National Marine Fisheries Service, Alaska Fisheries Science Center Observer Program database that were determined to be targeted on northern rockfish.

Year	CPUE (kg/h)	No. hauls targeted on NR
1990	4,515.5	67
1991	17,942.6	359
1992	5,758.0	369
1993	4,932.9	251
1994	7,568.5	276
1995	6,500.9	267
1996	7,264.3	141
1997	5,772.2	78
1998	9,093.9	78
All years comb.	8,544.7	1,886

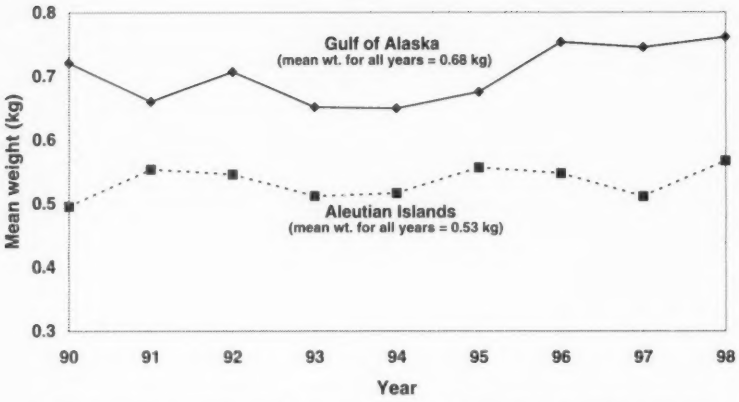

Figure 8.—Mean weight per fish of northern rockfish caught in the Gulf of Alaska and Aleutian Islands commercial fisheries, 1990–98, based on data collected by the National Marine Fisheries Service, Alaska Fisheries Science Center Observer Program.

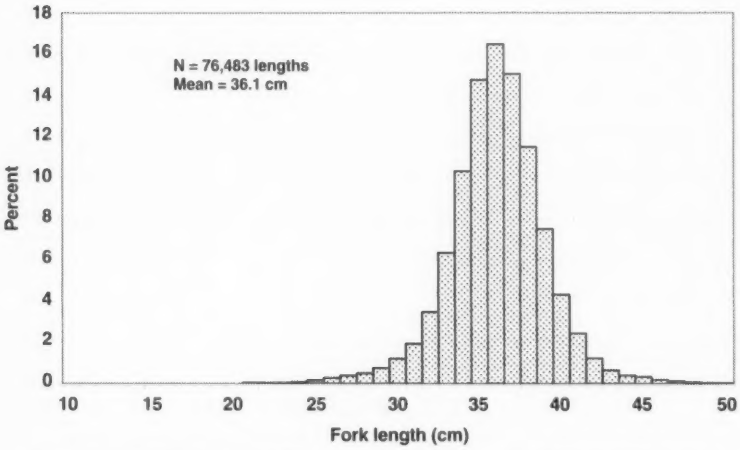

Figure 9.—Length frequency distribution of northern rockfish measured by observers in the Gulf of Alaska commercial fishery, 1990–98.

The highest CPUE for an individual haul was nearly 395,000 kg/h, which resulted from a catch of over 13,000 kg in a haul that was only 2 min in duration. Several other extremely large catches were seen from hauls that were less than 10 min long, which indicates that northern rockfish can sometimes be very densely aggregated.

A similar analysis was not done for northern rockfish CPUE in the Aleutian Islands because relatively few hauls in this region were identified as targeting on northern rockfish.

Trawl Surveys

Fishery-independent trawl surveys provide an alternative source of information on northern rockfish in Alaska. For this report, we examined data from six extensive bottom trawl surveys in the Gulf of Alaska and six in the Aleutian Islands (Table 12). These surveys were conducted by the AFSC's RACE Division from 1980 onward. The main objectives of the surveys in each region were to determine the distribution and abundance of principal groundfish and to collect ancillary biological information on these species, such as size, sex, and age composition. The surveys were conducted during the period May–September at depths ranging from about 10 to 500 m on the continental shelf and upper continental slope; in some years, depths to 1,000 m were sampled.

Each of the surveys used a stratified random design to select locations of trawl stations throughout each region, and fishing gear and procedures were standardized to allow comparisons between years. Standard duration of hauls on bottom was either 15 or 30 min, depending on the year, and detailed information was usually collected for each haul on width of the net opening and distance fished over the bottom. These measurements were used to calculate the area swept by the net over the bottom, and CPUE for species caught was then computed in terms of numbers and weight per square km. Biomass and population estimates were calculated by multiplying the mean CPUE's (kilogram per square km or numbers per square km) of each stratum by the stratum's areal size and summing the results to obtain estimates by management areas or by the total survey area (Wakabayashi et al., 1985). For more details on these surveys, the reader is referred to the following reports: Brown (1986); Harrison (1993); Ronholt et al. (1994); Stark and Clausen (1995); Martin and Clausen (1995); Martin (1997); and Britt and Martin (2001).

Bottom trawl surveys of the eastern Bering Sea have also been conducted by the RACE Division, but catches of northern rockfish have been exceedingly sparse. In a series of six surveys between 1979 and 1991, the largest biomass estimate for northern rockfish for the entire eastern Bering Sea region was only 53 t; two of the surveys reported no catches at all of northern rockfish (Ito et al., 1999). Because of this extremely limited information, we have chosen in this report to exclude analysis of RACE trawl survey data for northern rockfish in the eastern Bering Sea.

Survey Biomass Estimates

Biomass estimates for northern rockfish from the Gulf of Alaska and Aleutian Islands surveys suggest that the size of the northern rockfish resource in each region may be somewhat similar. Biomass estimates for the Gulf of Alaska have ranged from about 40,000 to 140,000 t between 1984 and 1996, and for the Aleutian Islands from about 40,000 to 190,000 t for the period 1980–97 (Fig. 12). One exception to this general similarity between regions is the 1999 biomass in the Gulf of Alaska of 242,000 t. This high biomass can be partially attributed to an extremely large catch of northern rockfish in one haul, so it may be an anomaly (Heifetz et al., 1999). More detailed information on these biomass estimates, especially concerning their precision and possible biases, may be found in annual rockfish stock assessments documents that were prepared for the NPFMC (e.g. Heifetz et al., 1994; Heifetz et al., 1999; and Ito et al., 1999).

Depth Distribution of Northern Rockfish in Surveys

An analysis of the depth distribution of northern rockfish in the surveys showed that in both the Gulf of Alaska and Aleutian Islands, northern rockfish were taken at generally similar depths, although the catches were distributed slightly deeper in the Aleutian Islands (Fig. 13). In the Gulf of Alaska, nearly all the catch came from depths between 50 and 200 m, with the majority (79.7%) in depths 75–150 m, and a peak at 100–125 m. In the Aleutian Islands, almost all the catch was taken at depths 75–200 m, with most (96.6%) at depths 75–175 m. In contrast to the Gulf of Alaska, no individual depth stratum predominated in the Aleutian Islands, and catches were rather evenly distributed at strata between 75 and 175 m. Shallow and deep extremes of northern rockfish distribution in the Gulf of Alaska surveys were 40 m and 649 m, respectively, and 62 m and 620 m, respectively, in the Aleutian Islands surveys.

Depth distribution of northern rockfish in the surveys was similar to that of the commercial fishery (compare Fig. 13 with Fig. 4). In the Gulf of Alaska, the

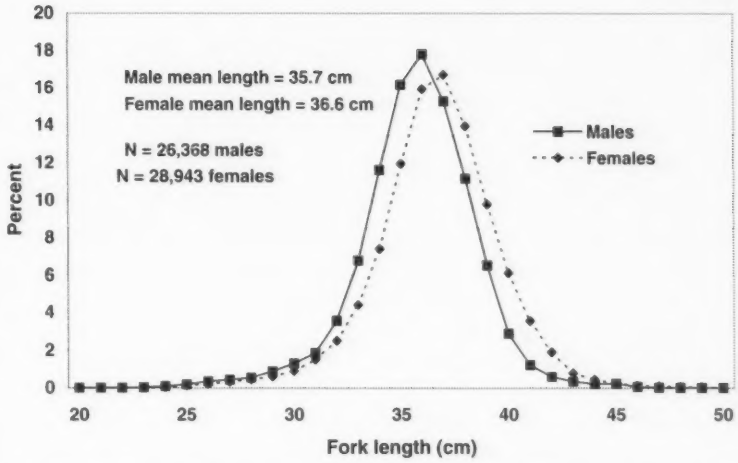

Figure 10.—Length frequency distribution, by sex, of northern rockfish measured by observers in the Gulf of Alaska commercial fishery, 1990–98.

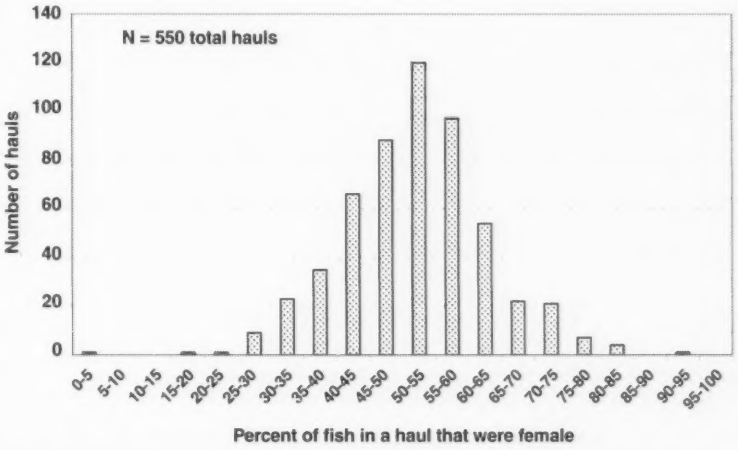

Figure 11.—Sex composition of northern rockfish in individual hauls determined by observers in the Gulf of Alaska commercial fishery, 1990–98. Hauls include only those in which sex was determined for ≥40 northern rockfish.

Table 12.—Summary of National Marine Fisheries Service bottom trawl surveys in the Gulf of Alaska and Aleutian Islands that were used in this report to provide information on northern rockfish (NR = northern rockfish).

Gulf of Alaska			Aleutian Islands		
Year of survey	No. of hauls	No. of hauls with NR catch	Year of survey	No. of hauls	No. of hauls with NR catch
1984	1,037	162	1980	435	120
1987	965	259	1983	425	159
1990	811	145	1986	499	155
1993	841	171	1991	379	131
1996	868	148	1994	449	128
1999	870	140	1997	498	158
All years	5,392	1,025	All years	2,685	851

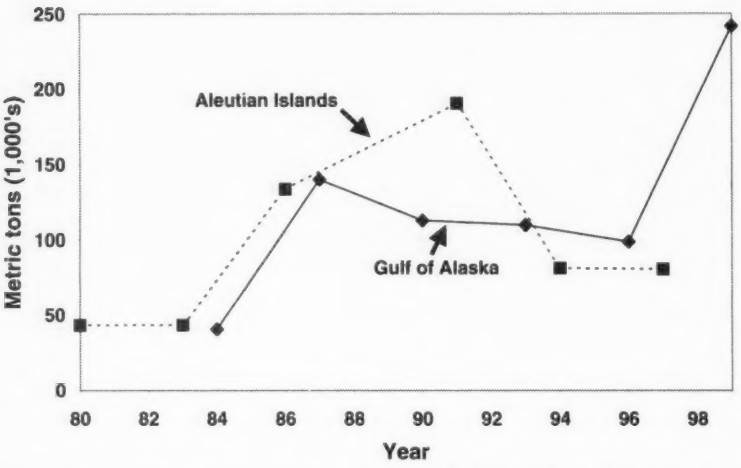

Figure 12.—Biomass estimates for northern rockfish in the Gulf of Alaska and Aleutian Islands, 1980–99, based on NMFS bottom trawl surveys.

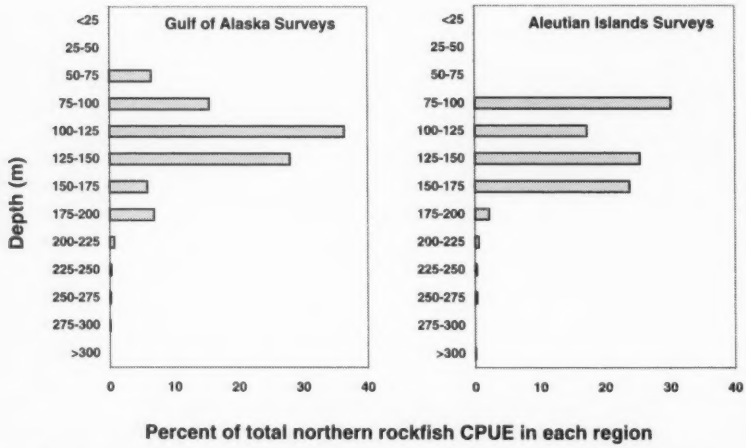

Figure 13.—Depth distribution of CPUE in kg/km^2 of northern rockfish in NMFS bottom trawl surveys of the Gulf of Alaska and Aleutian Islands, 1980–99.

fishery caught more fish at slightly shallower depths than did the surveys, but both data sources indicated that 80% or more of the catch came from depths of 75–150 m. Likewise, in the Aleutian Islands both the fishery and surveys agreed that around 90% or more of the fish were found in depths between 75 and 175 m. Both data sources also showed that catches were distributed a little deeper in the Aleutian Islands.

Geographic Distribution of Survey Catches and Comparison with Fishery Catches

Similar to the procedures used above in the analysis for the commercial fishery, a series of GIS plots was made to examine the geographic distribution of northern rockfish catches in the surveys. Plots of all survey hauls that reported any catch of northern rockfish, regardless of the amount, showed catches were widespread in both the Gulf of Alaska and Aleutian Islands (Fig. 14A and 15A). As in comparable plots for the commercial fishery (Fig. 5A and 6A), catches in the Gulf of Alaska tend to be more common on the outer continental shelf rather than inshore, whereas there is little discernible pattern to catches in the Aleutian Islands. Also, catches become more infrequent in the eastern Gulf of Alaska, and no fish were caught off southeastern Alaska.

To identify locations where northern rockfish were abundant in the surveys, additional plots were made for only those hauls with a relatively high CPUE (>5,000 kg/km^2) for northern rockfish (Fig. 14B and 15B). This amount was chosen so the plots would be comparable to those for the fishery (Fig. 5B and 6B) to determine where the catch was concentrated. A CPUE of 5,000 kg/km^2 is roughly equivalent to the 3,500 kg criterion we used in Figure 5B for plotting large catches of northern rockfish in the Gulf of Alaska fishery. (For a typical fishery haul, which uses commercial gear towed over the bottom for about 2 h, a catch of 3,500 kg approximately equals a CPUE of 5,000 kg/km^2.) Highest CPUE for any haul in the Gulf of Alaska was 405,438 kg/km^2, and in the Aleutian Islands, 180,943 kg/km^2. The hauls in Figures 14B and 15B accounted for most of the total northern rockfish CPUE in the surveys: for the Gulf of Alaska, they comprised 89.7% of the total CPUE for this species, and for the Aleutian Islands, 92.9%. For the Gulf of Alaska (Fig. 14B), these abundant catches were concentrated at various localities on the outer continental shelf just inside the 200 m depth curve. In the Aleutian Islands (Fig. 15B), hauls with large CPUE also were concentrated at several locations, but relatively few large catches were found in the eastern Aleutian Islands (i.e. the area east of Petrel Bank).

Locations of abundant northern rockfish catches in the fishery did not always coincide with those in the surveys, and vice versa. To compare these two data sources in terms of where most of the fish were caught, the major commercial fishing grounds identified previously in this report are superimposed on Figures

14B and 15B. In the Gulf of Alaska, the surveys and fishery agree that Portlock Bank and Davidson Bank are important fishing grounds for northern rockfish. Agreement is less certain, however, for the three remaining fishing grounds: Shumagin Bank, the Snakehead, and Albatross Bank. Several large catches in the surveys did occur within the latter three areas, but not enough to especially identify them as major areas of northern rockfish abundance. In particular, the Snakehead, which was the most important ground in the fishery, does not stand out in the survey catches. Furthermore, there is one area of high catches in the survey at the mouth of Shelikof Trough that had virtually no large fishery catches (compare Fig. 14B with Fig. 5B).

In the Aleutian Islands, a comparison between major fishing grounds in the fishery and large catches in the surveys also shows both similarities and differences (Fig. 15B). The fishery and survey data especially agree that Petrel Bank is an important area of northern rockfish abundance. To a lesser extent, there is also agreement that Tahoma Reef, Buldir Reef, Sturdevant Rock, and areas south of Amchitka Island and around Amlia Island are all localities of abundance. The survey data, however, does not show the large catches that were seen in the fishery for Ingenstrem Rocks, Buldir Island, the area southwest of Amchitka Island, Delarof Island, and Seguam Pass. In contrast, the surveys did show one location of abundance, Stalemate Bank, that was not evident from the fishery data.

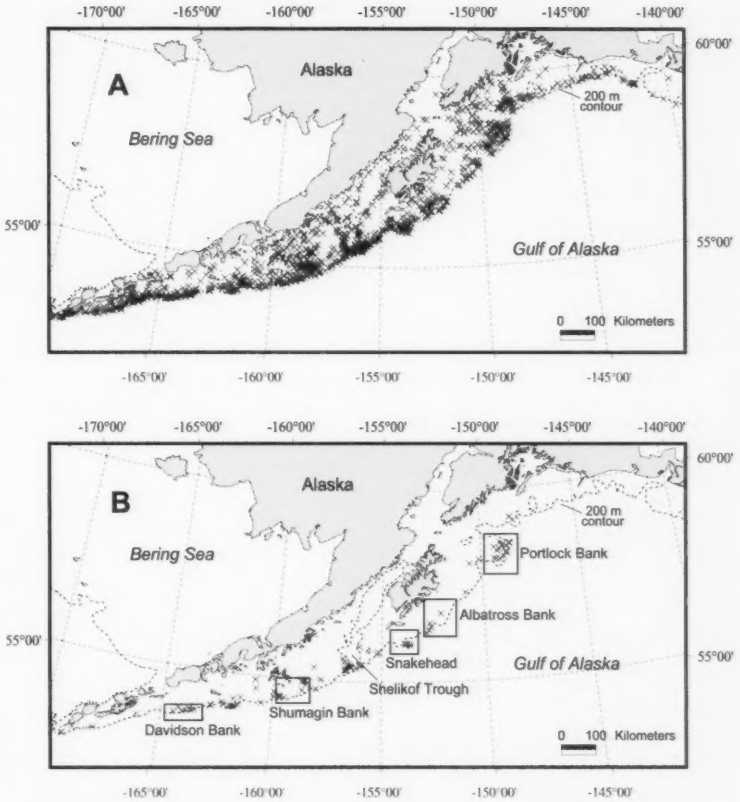

Figure 14.—Location of hauls that caught northern rockfish in NMFS bottom trawl surveys of the Gulf of Alaska, 1984–99. A: All hauls that caught northern rockfish; B: Hauls with a CPUE for northern rockfish of ≥5,000 kg/km^2. Also, the commercial fishing grounds for northern rockfish shown in Figure 5B have been superimposed on this plot.

Two factors may at least partially explain why the survey data did not always agree with the fishery data as to which fishing grounds are most important for northern rockfish:

1) The design of bottom trawls used in the fishery is considerably different than those used in the surveys. The fishery nets are of a relatively recent design that has been customized for catching large of amounts rockfish, and are generally of heavy-duty construction with "tire gear" on the footrope for towing over rough bottom. The survey nets have also been constructed for catching rockfish, but are an older design that does not use tire gear; they are also scaled down in size and weight so that relatively small trawlers chartered for the surveys are able to tow them. Consequently, the fishery nets are presumably more effective in catching rockfish over rougher substrates. If the preferred habitat of northern rockfish is rougher bottom (some evidence for this will be discussed later in this report), the survey nets, because of their lighter construction and lack of tire gear, would have more difficulty sampling this environment. Moreover, at many locations with very rough or steep bottoms, the survey nets cannot be fished at all, and these locations have remained unfished in the surveys. One possible hypothesis, therefore, would be that some locations within the boundaries of the fishing grounds may not be trawlable by the survey nets, and this could explain why the survey showed relatively few large catches at several of the grounds. However, when a comparison is made between Figure 14A (all catches of northern rockfish) and Figure 14B (large catches with fishing grounds superimposed) for an area such as the Snakehead, it is apparent that many survey hauls were successfully made within the Snakehead. Hence, the reason for the surveys having so few large catches in the Snakehead does not appear to be a simple inability to trawl this area due to the design of the survey's nets; other factors (particularly the one described

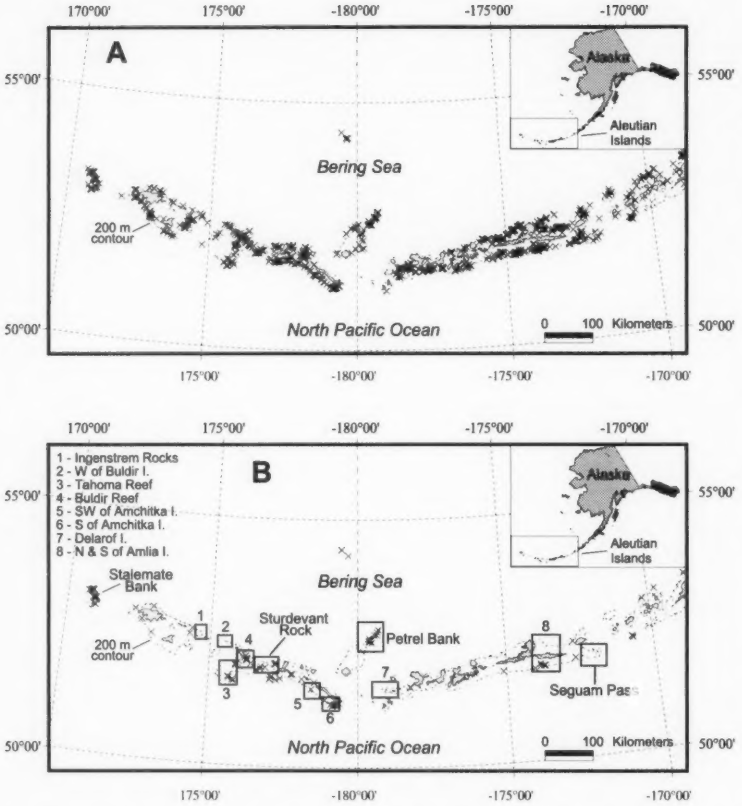

Figure 15.—Location of hauls that caught northern rockfish in NMFS bottom trawl surveys of the Aleutian Islands, 1980–97. A: All hauls that caught northern rockfish; B: Hauls with a CPUE for northern rockfish of ≥5,000 kg/km^2. Also, the commercial fishing grounds for northern rockfish shown in Figure 6B have been superimposed on this plot.

in the next paragraph) are likely more responsible for the survey's relatively low catch rates at this locality.

2) Commercial fishermen specifically search for and target large concentrations of northern rockfish, whereas haul locations in the surveys are selected randomly. When a fisherman finds a concentration of fish, he will repeatedly trawl at that vicinity as long as catches are good. However, when the surveys encounter a large catch, fishing is not continued at these localities; instead, the survey vessel moves on to the next random station, which may be many kilometers away. As a result of these different fishing strategies, the fishery would likely complete a much greater proportion of hauls with large catches at the fishing grounds than would the surveys.

The reason the surveys showed large catches of northern rockfish at the mouth of Shelikof Trough, whereas the fishery did not, cannot be easily explained. The fishery effort at this locality was relatively sparse in comparison to the large effort at the five major Gulf of Alaska fishing grounds, which may partially account for the scarcity of large fishery catches at Shelikof Trough. Still, enough hauls were made by the fishery at this locality (see Fig. 5A) that one would expect to find at least some large catches, based on the number of large catches seen here in the surveys. The surveys suggest that this area near the mouth of Shelikof Trough probably is a major area of northern rockfish concentration in the Gulf of Alaska, in addition to the five fishing grounds that were identified from the fishery data. Furthermore, it is interesting to note that examination of nautical charts for this site at the mouth of Shelikof Trough shows that its physical characteristics are very similar to those of the fishing grounds: the locality is an offshore bank of relatively shallow water which is surrounded by deeper depths.

Stalemate Bank was the only locality in the Aleutian Islands where large catches of northern rockfish were found in the surveys but not in the fishery. This difference is explained by the extremely low effort in this area by the fishery. Only two fishery hauls were found here that reported any catch of northern rockfish (Fig. 6A). Stalemate Bank is situated at the far western end of the Aleutian Islands, and the added expense of traveling to this isolated locality has probably deterred most fishermen from operating here. Stalemate Bank, however, definitely fits the geographic and physical pattern of so many of the other important fishing grounds, as it is far from land, surrounded by very deep water, and contains a substantial area of depth between 60 and 170 m, which corresponds to the preferred depths for northern rockfish found at the other grounds.

Substrate Preference for Northern Rockfish

Anecdotal observations from commercial fishermen and from scientists on trawl surveys indicate that northern rockfish are often caught in association with hard or rough substrates. To investigate the possibility that northern rockfish have a preference for rough substrates, we examined data on trawl performance of individual survey hauls to indirectly infer information on substrate type. (Actual data on substrate type were not collected for any hauls in the trawl surveys.) Of the 20 hauls in the Gulf of Alaska with the highest CPUE for northern rockfish, 5 (25%) were assigned a performance code of "unsatisfactory" in the database because the net hung up on the bottom

and/or was damaged. This compares with a total of only 5.7% that were assigned an unsatisfactory code for all hauls with any northern rockfish catch. In particular, three of the top four hauls in terms of CPUE were unsatisfactory tows in which the net hung up severely on the bottom. Such hang-ups are nearly always an indication of a hard, rocky, and/or steep bottom. The performance data, therefore, suggest that at least some large catches of northern rockfish appear to be associated with hard substrates.

Performance data from the trawl surveys in the Aleutian Islands are more equivocal in regards to large catches of northern rockfish being associated with rough substrate. Similar to the Gulf of Alaska, the haul with the highest northern rockfish CPUE of any in the Aleutian surveys was an "unsatisfactory" tow in which the net severely hung on the bottom. However, this was the only unsatisfactory haul among the top twenty tows in terms of CPUE. Overall, 3.3% of the survey hauls in this region that had catches of northern rockfish were rated as unsatisfactory because of hang-ups or net damage.

Although strong evidence was not apparent in the Aleutian Islands surveys of a northern rockfish association with hard substrate, the nature of the fishery in this region suggests that a relationship does exist between northern rockfish and hard substrates. As discussed previously in this paper, most of the northern rockfish catch in the Aleutian Islands has been taken as bycatch in the Atka mackerel fishery. This fishery is known to occur primarily over rocky, uneven bottom (NPFMC, 1998), and the northern rockfish caught in this fishery are presumably also taken in this habitat.

Size Composition of Northern Rockfish in Surveys

In each survey, length frequency data were collected for northern rockfish in individual hauls, and these data were later expanded over the entire survey area and weighted by the estimated population size to yield estimated population size compositions. Wakabayashi et al. (1985) provide a detailed explanation of the computations used in this procedure.

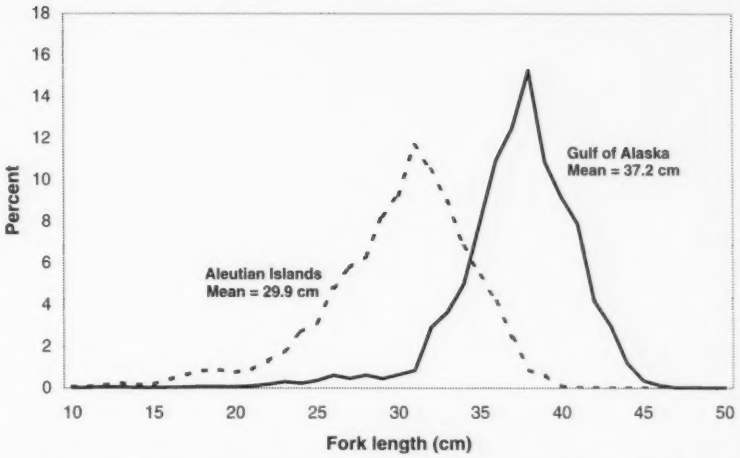

Figure 16.—Estimated population size compositions for northern rockfish in the Gulf of Alaska and Aleutian Islands, based on NMFS bottom trawl surveys in each region. Gulf of Alaska size compositions are from combined results of the 1993, 1996, and 1999 surveys; Aleutian Islands size compositions are from combined results of the 1991, 1994, and 1997 surveys.

Figure 16 shows a comparison for the size composition of northern rockfish between the Gulf of Alaska and Aleutian Islands surveys. This comparison is only for the last three surveys combined in each region because valid population size composition information is not available for the Aleutian surveys before 1991. The figure clearly shows that average length of northern rockfish is significantly greater in the Gulf of Alaska. Overall mean population length in the Gulf of Alaska was estimated to be 37.2 cm, as compared to only 29.9 cm in the Aleutian Islands. Virtually none of the population in the Aleutians Islands was greater than 40 cm in length, whereas about 26% of the Gulf of Alaska population was in this size category. These results are very similar to those presented earlier for size of fish taken in the commercial fishery, which also showed substantially larger fish were caught in the Gulf of Alaska.

Population size compositions for individual surveys in the Gulf of Alaska (Fig. 17) indicate that, in general, the surveys have taken relatively few small northern rockfish. Fish less than 30 cm in length were rarely caught in the last three surveys, and fish this size were also relatively sparse in the 1987 and 1990 surveys. Only the 1984 survey showed a substantial portion of the sampled population to be less than 30 cm in length. This lack of small fish in the surveys may be an indication that recruitment of young northern rockfish is a relatively uncommon event; alternatively, it may indicate that young fish reside in a habitat that is not effectively sampled by the survey's trawls.

Length frequency distributions of northern rockfish that were sexed in the surveys show that females averaged 1.3 and 1.7 cm larger than males in the Gulf of Alaska and the Aleutian Islands, respectively (Fig. 18). *T*-tests showed these differences were both highly significant (Gulf of Alaska, $P < 0.0001$, $t = 7.31$, df = 29,334; Aleutian Islands, $P < 0.0001$, $t = 9.96$, df = 32,259). These results are similar to those presented earlier for the Gulf of Alaska fishery data, which likewise indicated females were larger than males. Studies of most other *Sebastes* species have also shown that average length of females is greater than that of males (Lenarz and Wyllie Echeverria, 1991) probably because there is an evolutionary advantage for females to be larger and produce more eggs.

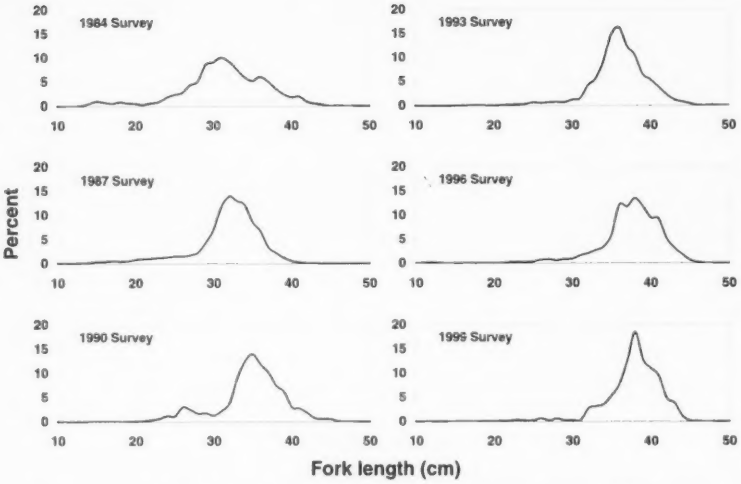

Figure 17.—Estimated population size compositions for northern rockfish in the Gulf of Alaska, based on NMFS bottom trawl surveys.

Maximum Length of Northern Rockfish in Surveys

Previous publications that are commonly used to identify rockfish in Alaska (e.g. Eschmeyer et al., 1983; Kramer and O'Connell, 1995; Orr et al., 2000; Mecklenburg et al., 2002) all list maximum length for northern rockfish as ranging from 38 to 41 cm FL, depending on the publication. This maximum length is erroneous for the Gulf of Alaska, as shown by the population size compositions for this region in Figure 16. Many individuals in the Gulf of Alaska surveys have measured between 40 and 45 cm FL. The maximum fork length observed for northern rockfish in all the Gulf of Alaska surveys was 48 cm, and, as previously mentioned, 26% of the estimated population for the combined 1991, 1994, and 1997 surveys was greater than 40 cm FL. Individual northern rockfish greater than 40 cm FL are also relatively common in the Gulf of Alaska commercial fishery (Fig. 9).

Locations and Depths of Juvenile Northern Rockfish in Surveys

Although small northern rockfish were only taken infrequently in the surveys, those that were caught provide some information as to where juveniles of this species may be found. A GIS plot of hauls in the Gulf of Alaska where small (≤25 cm FL) juvenile northern rockfish were caught shows that fish of this size were taken at many locations on the continental shelf (Fig. 19). In contrast to Figure 14A, which shows locations of all hauls that caught northern rockfish, the hauls that reported catches of these small fish tend to be more inshore and not as concentrated on the outer continental shelf. To identify locations where juvenile northern rockfish were especially abundant, Figure 19 also shows hauls in which 20 or more small fish (≤25 cm FL) were measured. The plot indicates that relatively few hauls met this criterion, and is additional evidence that juvenile northern rockfish have generally not been well sampled in the surveys. It does show, however, that locations in the surveys where small fish were caught in larger numbers tend to be distributed across the continental shelf and are not particularly concentrated on the outer shelf, as are adults. This tendency of small fish to be found more inshore than larger adults is also illustrated in Figure 20. This plot shows that catches of large adult fish (mean fork length ≥35 cm) are usually located on the outer continental shelf, whereas hauls in which smaller fish (mean fork length ≤30 cm) predominate are mostly located at more inshore localities throughout the shelf.

We also investigated the relationship between size of northern rockfish and depth of capture in the Gulf of Alaska surveys (Fig. 21). As might be expected given the more inshore distribution of smaller fish described in the previous paragraph, hauls in which the mean length of northern rockfish was less than about 28 cm FL were mostly found at relatively shallow depths less than 100 m. In contrast, hauls in which the mean fork length was greater than about 30 cm were located at a wide range of depths from around 70 to 300 m. This general bathymetric cline in size is also typical of other *Sebastes* species inhabiting the continental shelf and slope of the Gulf of Alaska (Major and Shippen, 1970; Martin and Clausen, 1995; Martin, 1997; Britt and Martin, 2001). In summary, the Gulf of Alaska surveys indicate that juvenile northern rockfish are generally found more inshore and at shallower depths than are larger adult fish.

To examine the distribution of juvenile northern rockfish in the Aleutian Islands surveys, we made a series of GIS plots and a depth graph analogous to those for the Gulf of Alaska surveys (Fig. 22–23, Fig. 21). (Because of the smaller size of northern rockfish in the Aleutian Islands, we chose to plot hauls with a mean northern rockfish length ≤25 cm FL and those with a mean length ≥30 cm FL in Figure 23, instead of ≤30 cm FL and ≥35 cm FL as was done for the Gulf of Alaska in Figure 20.)

In contrast to the Gulf of Alaska data, the Aleutian Islands surveys do not show much difference in geographic distribution between juvenile and adult northern rockfish. Figure 22 shows that small (≤25 cm FL) juvenile northern rockfish have been taken in at least small amounts at many locations throughout the Aleutian Islands, but that larger numbers of juveniles have only been caught infrequently in the surveys.

A comparison between Figure 22 and Figure 15A (Figure 15A shows all catches of northern rockfish in the surveys) indicates that smaller northern rockfish do not have a noticeably differ-

ent pattern of distribution than the overall population. This is further demonstrated in Figure 23, which shows that concentrations of small and large northern rockfish appear to mostly overlap in their distributions. Finally, the depth versus length graph for the Aleutian Islands in Figure 21 also does not indicate much difference in depth distribution between hauls with small or large fish.

The reason that smaller northern rockfish had a different distribution than larger fish in the Gulf of Alaska, but did not in the Aleutian Islands, may be related to the distinct bathymetric characteristics of each region. The Aleutian Islands do not have the broad continental shelf found in the Gulf of Alaska; instead, at most places in the Aleutian Islands, the bottom drops steeply from the shore to very deep depths in just a short distance. Because of the limited amount of shallow-water habitat in the Aleutian Islands, it may be necessary for juvenile northern rockfish to live in closer proximity to adult fish than is the case in the Gulf of Alaska.

Sex Ratio of Northern Rockfish in Surveys

Sex was determined in the surveys for nearly all the northern rockfish that were sampled for length frequencies. Sex compositions in the surveys indicate that the sex ratio was nearly equal in the Gulf of Alaska, but females predominated in the Aleutian Islands (Table 13). For all years combined in the Gulf of Alaska, 49.2% of the fish sampled were males, and 50.8% were females. There was some variation in the sex ratios between individual surveys in this region, however, with females ranging from 58% in 1984 to 45% in 1999. For all years combined in the Aleutian Islands, males comprised 42.9% and females 57.1% of all northern rockfish sampled. The predominance of females was consistent in all the Aleutian Islands surveys.

To analyze whether the sex ratios for all years combined in each region were significantly different from 50:50, we used the same statistical procedure as we used previously for the pooled sex ratio data in the Gulf of Alaska fishery, replicated tests of goodness of fit (Sokal and Rohlf, 1969). Results of these tests indicated that the sex ratio differed significantly from 50:50 in both the Gulf of Alaska and the Aleutian Islands (Gulf of Alaska: chi-square = 10.8; df = 1; $P <$

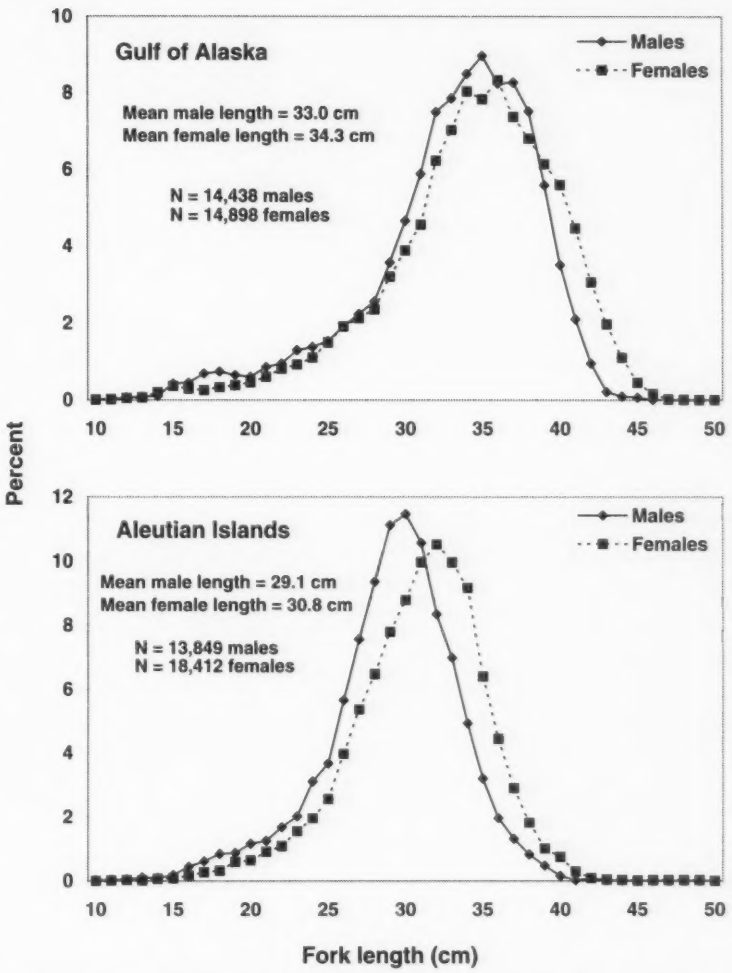

Figure 18.—Length frequency distribution, by sex, of northern rockfish measured in NMFS bottom trawl surveys in the Gulf of Alaska and Aleutian Islands, 1980–99.

Table 13.—Sex composition of northern rockfish sampled in NMFS bottom trawl surveys of the Gulf of Alaska and Aleutian Islands, 1980–99.

Gulf of Alaska surveys				Aleutian Island surveys			
Year	No. sexed	% male	% female	Year	No. sexed	% male	% female
1984	4,312	41.8	58.2	1980	1,539	42.6	57.4
1987	8,188	48.5	51.5	1983	6,535	42.3	57.7
1990	3,488	53.8	46.2	1986	5,881	47.2	52.8
1993	5,306	50.4	49.6	1991	4,853	45.2	54.8
1996	4,449	47.9	52.1	1994	6,250	38.4	61.6
1999	3,593	55.2	44.8	1997	7,461	42.2	57.8
Total	29,336	49.2	50.8	Total	32,519	42.9	57.1

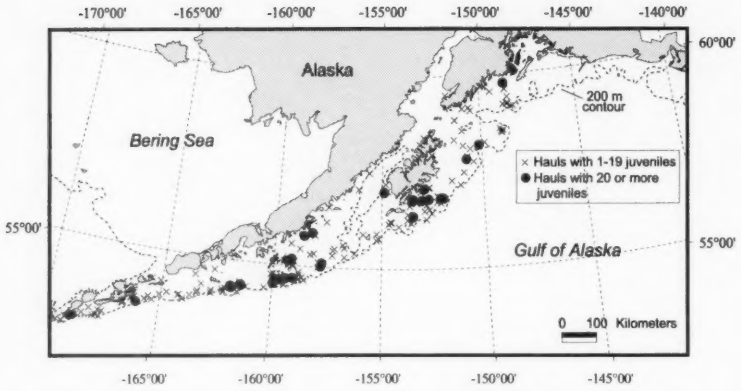

Figure 19.—Location of hauls in which small (≤25 cm FL) juvenile northern rockfish were measured in NMFS bottom trawl surveys of the Gulf of Alaska, 1984–99.

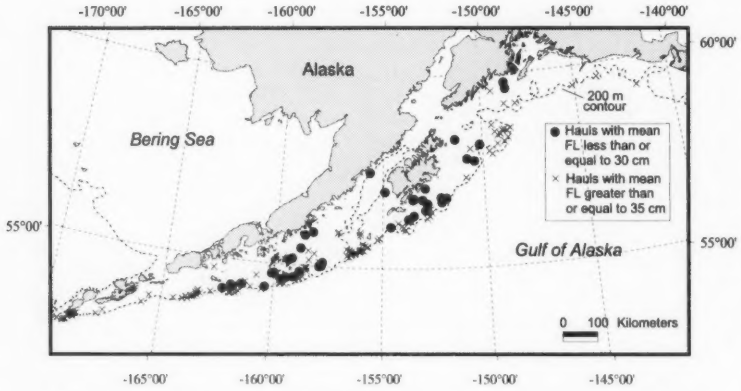

Figure 20.—Comparison of haul locations for small vs. large northern rockfish in NMFS bottom trawl surveys of the Gulf of Alaska, 1984–99. Hauls with "small" northern rockfish are those in which mean fork length was ≤30 cm; hauls with "large" northern rockfish are those in which mean fork length was ≥35 cm (plot only includes hauls in which ≥20 northern rockfish were measured).

0.01; Aleutian Islands: chi-square = 664.6; df = 1; $P < 0.0001$). Thus, in both regions, there appeared to be significantly more females in the population.

A comparison between the fishery and survey data for overall sex ratio in the Gulf of Alaska indicates that the fishery data also showed a significantly higher percentage of females (see previous section "Sex Ratio of Fish Caught in the Gulf of Alaska Fishery"). These statistical significances for the Gulf of Alaska, however, may not be of much biological importance. For each data source, the pooled sex ratio for all years combined was reasonably uniform (male/female ratios were 48:52 and 49:51 in the fishery and surveys, respectively), and the fact that females were significantly more abundant in our analysis may be a reflection mainly of the large sample size of fish that were sexed in both the fishery and the surveys. Other species of *Sebastes* have also been reported to have an overall sex ratio of 50:50. For example, Major and Shippen (1970) concluded that for Pacific ocean perch, "sex ratio, although it varies considerably with time of year and from sample to sample, probably is 1:1".

Our results for the Aleutian Islands surveys, however, were different in that they showed a clear predominance of female northern rockfish in this region. The reason for this difference is unknown.

The same methods we used previously to analyze sex ratios in the Gulf of Alaska fishery were also used to examine the sex composition of northern rockfish in individual survey hauls. Again, we selected only those hauls in which sex was determined for at least 40 northern rockfish. A considerable number of hauls differed substantially from a 50:50 sex ratio (Fig. 24). For example, in the Gulf of Alaska, there were nine hauls in which females comprised <20%, and in the Aleutian Islands, the catch in eleven hauls was 85% or more females. Replicated tests of goodness of fit among hauls indicated heterogeneity of sex ratios among hauls was highly significant in both regions (Gulf of Alaska: chi-square = 3,195.8; df = 198; $P < 0.0001$; Aleutian Islands: chi-square = 3,289.8.; df = 200; $P < 0.0001$). Despite this very high heterogeneity, chi-square tests for individual hauls showed that 37% of the hauls in both the Gulf of Alaska and Aleutian Islands had a sex ratio that was not significantly different than 50:50. We conclude that during the summer months (when the surveys were conducted), the sex ratio of northern rockfish is highly dependent upon the specific location that is sampled, and that some degree of localized aggregation by sex often occurs.

Age and Growth of Northern Rockfish Based on Survey Samples

Ages have been determined for northern rockfish sampled in five of the surveys in the Gulf of Alaska and three in the Aleutian Islands (Table 14). In each of these surveys, otolith pairs were collected from a subsample of male and female northern rockfish in selected hauls, usually those with a large catch of this species. Generally, about 10–30 fish of each sex were sampled per haul, although sometimes fewer were sampled. Attempts were made to disperse the

sampled hauls over the survey area so the samples were not concentrated in one locality. All ages were determined for the otoliths by the "break-and-burn" method (Beamish, 1979).

Similar to aging studies of most other rockfish species (Archibald et al., 1981; Pearson et al., 1991; Bechtol, 2000), there was a large variation in length-at-age amongst individual fish (Fig. 25). The maximum age of northern rockfish was 44 years in the Gulf of Alaska and 72 years in the Aleutian Islands (Table 14). Based on these results, we computed von Bertalanffy growth parameters for males, females, and sexes combined for both the Gulf of Alaska and the Aleutian Islands (Table 15).

The growth curves based on these parameters indicate that growth of northern rockfish in the Gulf of Alaska is considerably different than in the Aleutian Islands (Fig. 26). Gulf of Alaska fish of both sexes appear to grow faster when young and reach a larger maximum size. To test the significance of this apparent regional difference in growth, and to also test possible differences in growth by sex, we used the *F*-test procedure in Quinn and Deriso (1999). This procedure tests whether a "full" model with separate growth parameters for each data set is significantly different from the "reduced" model with common parameters among data sets. The *F*-statistic is

$$F = \frac{RSS_y - RSS_x}{f_y - f_x} / \hat{\sigma}_x^2$$

where RSS_y is the residual sums of squares for fitting a reduced model, RSS_x is the residual sums of squares of fitting the full model, f_y is the degrees of freedom for the reduced model, and f_x is the degrees of freedom for the full model, and $\hat{\sigma}_x^2$ is the residual mean square. If there are R data sets, p parameters, and n data points, then $f_x = n - Rp$, $f_y = n - p$, and $\hat{\sigma}_x^2 = RSS_x / f_x$. The F-statistic is compared to the $F_{crit}(f_y - f_x, f_x, \alpha)$. Results of the F-tests indicated there were highly significant ($P < 0.001$) differences in growth between regions and sexes (Table 15). For the data pooled among sexes, the estimated asymptotic size (L_∞) was 39.2 cm

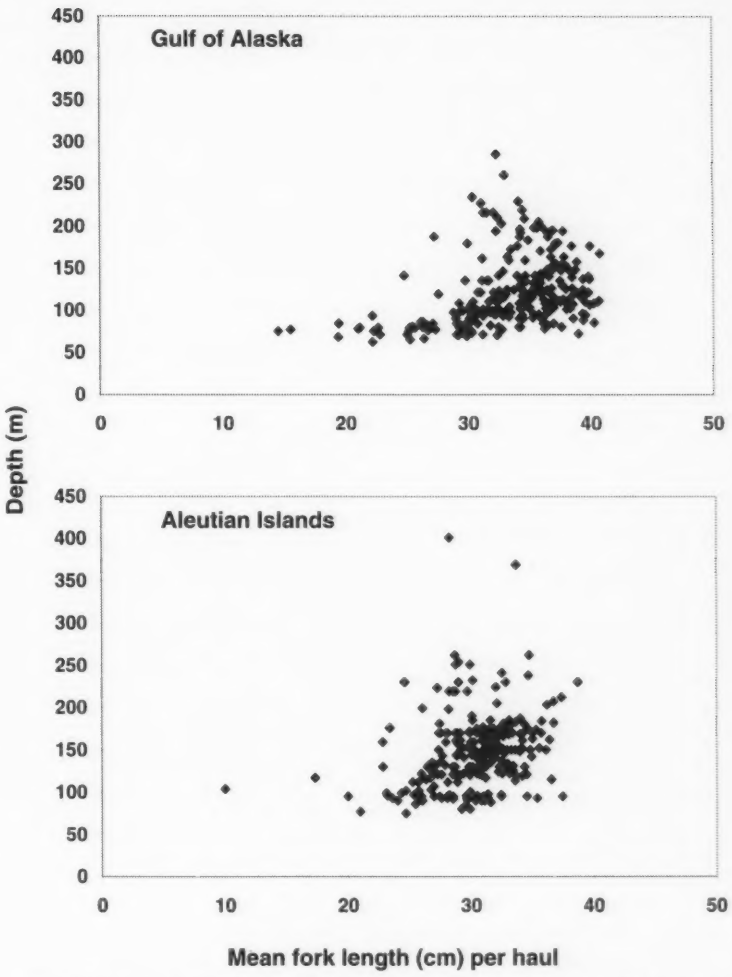

Figure 21.—Depth vs. length relationship for northern rockfish in NMFS bottom trawl surveys of the Gulf of Alaska and Aleutian Islands, 1980–99 (plot only includes hauls in which ≥20 northern rockfish were measured).

Table 14.—Summary of northern rockfish age samples from NMFS bottom trawl surveys in the Gulf of Alaska and Aleutian Islands that were analyzed in this report.

Region and year	No. of hauls sampled	Total no. of fish aged	No. of males aged	No. of females aged	Min. age	Max. age
Gulf of Alaska						
1984	6	356	175	181	5	43
1987	17	497	235	262	3	44
1990	13	439	202	237	2	33
1993	20	354	173	181	2	40
1996	19	462	248	214	2	43
Total	75	2,108	1,033	1,075	2	44
Aleutian Islands						
1986	18	565	279	286	4	57
1994	19	409	195	214	3	66
1997	67	630	301	329	2	72
Total	104	1,604	775	829	2	72

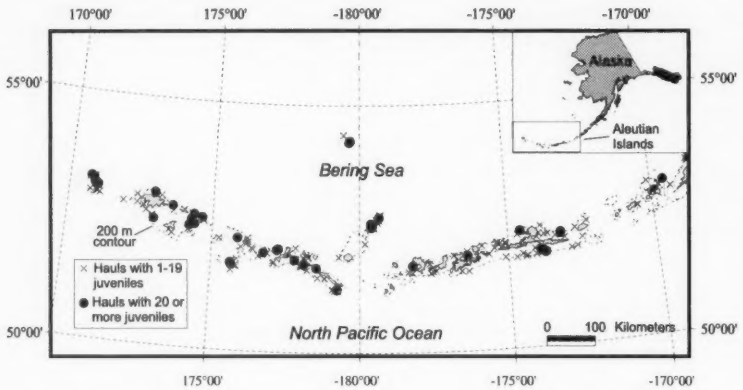

Figure 22.—Location of hauls in which small (≤25 cm FL) juvenile northern rockfish were measured in NMFS bottom trawl surveys of the Aleutian Islands, 1980–97.

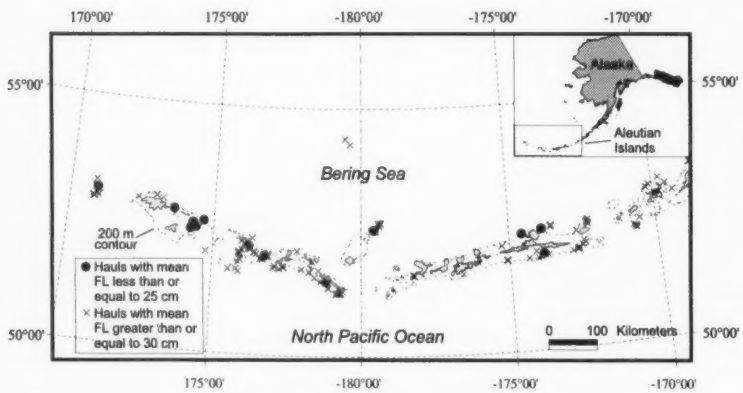

Figure 23.—Comparison of haul locations for small vs. large northern rockfish in NMFS bottom trawl surveys of the Aleutian Islands, 1980–97. Hauls with "small" northern rockfish are those in which mean fork length was ≤25 cm; hauls with "large" northern rockfish are those in which mean fork length was ≥30 cm (plot only includes hauls in which ≥20 northern rockfish were measured).

in the Gulf of Alaska and only 33.7 cm in the Aleutian Islands. Females in both areas had a larger asymptotic size than males with divergence in size at about age 10. The asymptotic size was 37.8 cm and 40.2 cm for Gulf of Alaska males and females, respectively, and 32.6 cm and 34.5 cm for Aleutian Islands males and females, respectively.

Summary and Conclusions

In this report, we analyzed data from the U.S. commercial fishery (collected by observers) and from AFSC bottom trawl surveys to describe the fishery for northern rockfish in Alaska and to provide information on distribution and biology of northern rockfish. Although the amount of northern rockfish catch in both the Gulf of Alaska and the Aleutian Islands has been similar in recent years, the fishery in each region is very different.

In the Gulf of Alaska, most of the catch is taken in a directed fishery for northern rockfish in which the catch is retained for processing and subsequent sale. In the Aleutian Islands, however, the catch predominantly comes as bycatch in the Atka mackerel fishery, and most northern rockfish are discarded.

In both regions, nearly all the catch is the result of bottom trawling. In the Aleutian Islands, this trawl catch has been exclusively taken by factory-trawlers. Factory-trawlers have also predominated in the Gulf of Alaska fishery, but since 1996, smaller shore-based trawlers operating from the port of Kodiak have also taken a substantial portion of the catch. Commercial catch of northern rockfish in the eastern Bering Sea has generally been insignificant compared to that in the Gulf of Alaska and Aleutian Islands, especially in recent years.

The fishery and survey data provide much information on the geographic distribution of adult northern rockfish. Adults in the Gulf of Alaska, and to a lesser degree also in the Aleutian Islands, are mostly found on relatively shallow, offshore banks of the outer continental shelf that are relatively small in size. The major fishing grounds in the Gulf of Alaska correspond to five of these banks that together accounted for an estimated 89% of the Gulfwide catch of northern rockfish in the years 1990–98: Portlock Bank, Albatross Bank, the Snakehead, Shumagin Bank, and Davidson Bank. Of these, the Snakehead has been the most important and has yielded nearly 46% of the catch during these years. Survey data indicate that one other bank at the mouth of Shelikof Trough is also an area of northern rockfish abundance, but for unknown reasons little commercial catch has been taken at this site. These banks are all characterized by their offshore locations near the start of the continental slope, relatively shallow depths of 75–150 m, and the fact that they are rises or humps surrounded by deeper water.

Of the 11 major fishing grounds for northern rockfish identified in the Aleutian Islands, several are also offshore banks similar to those in the Gulf of Alaska. These include Seguam Pass, Petrel Bank, and Tahoma Reef. Other fishing grounds in the Aleutian Islands are closer to shore and are not rises or humps, and therefore differ from the Gulf grounds in terms of their physi-

cal characteristics. Combined, these 11 grounds produced an estimated 84% of the northern rockfish catch in the Aleutians Islands during the period 1990–98. Depths of northern rockfish catches on fishing grounds in the Aleutian Islands are slightly deeper than in the Gulf, and range from 75 to 175 m. One other area of northern rockfish abundance was found in the Aleutian surveys but not in the fishery: Stalemate Bank at the far western end of the Aleutian chain. For the relatively small catch of northern rockfish in the eastern Bering Sea, only one important fishing ground was identified, near Southeast Zhemchug Canyon.

In addition to these geographic preferences for northern rockfish, other indications of their preferred adult habitat can be inferred from fishery and survey data. The fishery data suggest that adult northern rockfish are mostly demersal in their distribution, as virtually all the catch has been taken by bottom trawls fished on or near the bottom, and very few fish have been caught in mid-water or by pelagic trawls. The survey data for the Gulf of Alaska suggest that large catches of northern rockfish may be associated with rocky and steep habitats. Further evidence of a rocky habitat for northern rockfish comes from the fact that these fish in the Aleutian Islands are predominantly caught as bycatch in the fishery for Atka mackerel, which takes place mostly over rough bottoms. Additional research is needed, however, to definitively confirm that northern rockfish prefer a demersal, rocky bottom habitat.

Although the fishery and survey data generally agree regarding the geographic distribution and abundance of northern rockfish, there are some discrepancies between the two data sources as to the specific localities of abundance. Albatross Bank, Shumagin Bank, and especially the Snakehead were identified as major grounds for northern rockfish in the Gulf of Alaska fishery, but relatively few large catches were found there in the surveys. Similarly, several of the fishing grounds found in the Aleutian Islands did not show abundant catches of northern rockfish in the surveys.

Regarding these discrepancies, it is likely the fishery data in general show a more accurate picture of where northern rockfish are most abundant. The number of hauls with catches of northern rockfish is much larger in the fishery data, the commercial trawl gear is stronger and more modern in design than the gear in the surveys and is therefore more effective at catching rockfish, and commercial fishermen especially seek out locations of northern rockfish abundance. The surveys, however, did show two locations of northern rockfish abundance that were not evident in the fishery.

The survey data indicate that small, juvenile northern rockfish in the Gulf of Alaska tend to live more inshore and at shallower depths than adults. In the Aleutian Islands surveys, there appeared to be little difference in the distribution of juveniles and adults. However, catches of juveniles in the surveys of both regions were generally sparse, and studies specifically directed toward young fish

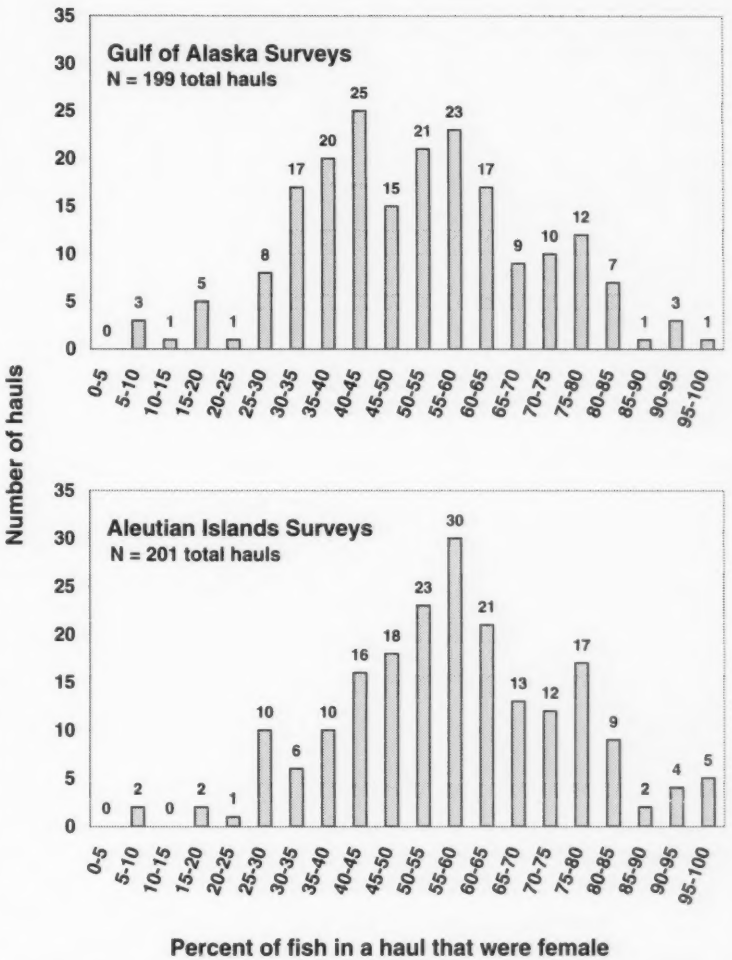

Figure 24.—Sex composition of northern rockfish in individual hauls of NMFS bottom trawl surveys of the Gulf of Alaska and Aleutian Islands, 1980–1999. Hauls include only those in which sex was determined for ≥40 northern rockfish.

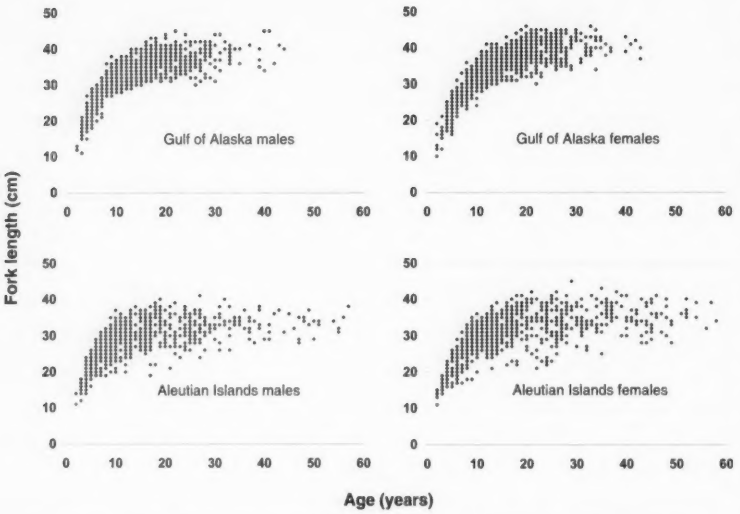

Figure 25.—Length vs. age results for northern rockfish age samples collected in NMFS bottom trawl surveys of the Gulf of Alaska and Aleutian Islands. Gulf of Alaska results are from the 1984, 1987, 1990, 1993, and 1996 surveys; Aleutian Islands results are from the 1986, 1994, and 1997 surveys. Each data point represents the length and age of an individual fish. Where more than one fish had the same length and age, data points have been plotted on top of each other and appear as a single point.

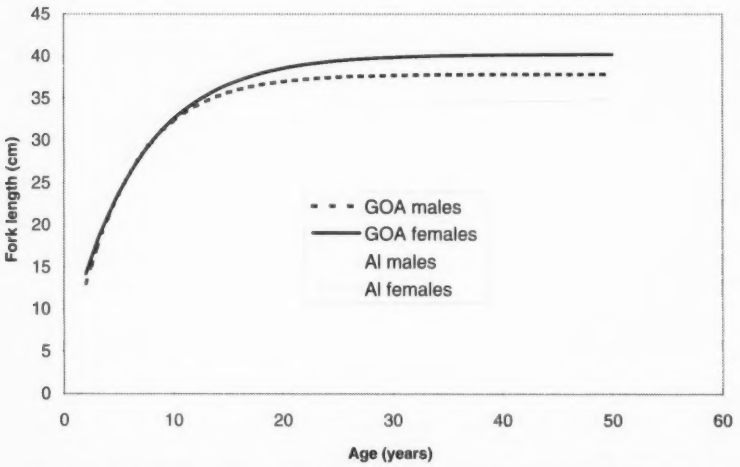

Figure 26.—Growth curves for male and female northern rockfish in the Gulf of Alaska (GOA) and Aleutian Islands (AI), based on the von Bertalanffy growth parameters given in Table 15.

will probably be necessary to better determine their distribution and habitat requirements.

Sex ratio of northern rockfish in the Gulf of Alaska appears to be close to 50:50 based on both fishery and survey data. In contrast, females in the Aleutian Islands appear to predominate; surveys there indicated a female/male ratio of 57:43. Why the sex ratios were so different in each region is unknown. Sex ratios in individual hauls of surveys in both regions often differed significantly from 50:50, which indicates some degree of aggregation by sex at certain localities and/or times.

Both the fishery and the surveys show that northern rockfish are significantly larger in the Gulf of Alaska than in the Aleutian Islands, and that females are significantly larger than males in each region. The small size of northern rockfish in the Aleutian Islands has likely been a major cause of the high discard rate for these fish in this region's fishery. This size difference between the two regions was further confirmed by our age and growth analysis, which showed Gulf of Alaska fish grew significantly faster and reached a larger maximum size.

The large difference between the Gulf of Alaska and Aleutian Islands in size and growth of northern rockfish suggests that separate populations may exist in each region. However, a preliminary genetics study of northern rockfish sampled from three localities in Alaska waters (around Kodiak Island, the central Aleutian Islands, and the western Aleutian Islands) found no evidence of stock structure (Gharrett et al.[4]). Because of the limited scope of this latter study, a more thorough genetic or morphometric study may be warranted to determine if subpopulations of northern rockfish occur in Alaska.

Acknowledgments

We especially thank Betty Goetz and her staff at the AFSC's Resource Ecology and Fishery Management Division's Age and Growth Task in Seattle, who aged all the northern rockfish that were used in this study's growth analysis. We also thank the following individuals for helpfully providing descriptive information about the northern rockfish commercial fishery: Andy Smoker, Eric Hollis, Laurie Bowen, Tim Meintz, and Chris Blackburn (for affiliations, see footnotes 7, 8, and 9).

Table 15.—Von Bertalanffy parameter estimates of non-linear least squares fit to northern rockfish age and length data, and *F*-tests for comparison of growth models by region and sex. Northern rockfish age and length data were based on the samples listed in Table 14.

		Gulf of Alaska			Aleutian Islands		
Parameter	Pooled[1]	Male	Female	Pooled[2]	Male	Female	Pooled[2]
n	3,712	1,033	1,075	2,108	775	829	1,604
L_∞	36.3	37.8	40.2	39.2	32.6	34.5	33.7
k	0.189	0.187	0.152	0.165	0.214	0.175	0.188
t_0	−0.179	−0.262	−0.870	−0.636	0.100	−0.562	−0.303
***F*-tests:**	**By region**		**Gulf of Alaska by sex**			**Aleutian Islands by sex**	
RSSy	5029826		1572479			1945986	
RSSx	3518465		1512591			1899649	
σ_x^2	949.4		719.6			1188.8	
f_y	3709		2105			1601	
f_x	3706		2102			1598	
F-statistic	530.6		27.7			13.0	
P	6.9E-287		1.4E-17			2.2E-08	

[1] Pooled = Gulf of Alaska and Aleutian Islands data combined for both sexes.

[2] Pooled = male and female data combined.

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Measuring Fishing Capacity and Utilization with Commonly Available Data: An Application to Alaska Fisheries

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Introduction

Current regulations limit the amount of time catcher vessels and catcher-processor vessels may fish, which often precludes vessels from operating at their full, productive capacity (Weninger and Strand, 2003). At present, it's unclear what the level of catch would be if the existing fleet of vessels that operate in Federally managed Alaska fisheries were allowed to fish for longer periods of time during the year (under normal operating conditions).[1] A first step toward addressing this question is to compare existing capacity to actual catch. A significant difference between the two indicates that there is likely more investment in the fishery than that which maximizes the net benefits to the nation, and it may signal the need for implementing measures to diminish or eliminate the incentives for, and presence of, excess capacity (FAO, 1998).[2]

The process of estimating potential catch, in the presence of regulations, essentially requires one to examine past and present fishing activity to determine the extent to which current effort, and catch, could and/or would increase if existing conditions or regulations changed.[3] The capacity measures computed in this paper were constructed using data on catch (in metric tons, (t)), participation (in weeks), and vessel characteristics of catcher vessels and catcher-processor vessels that operated in Federally managed Alaska commercial fisheries from 1990 to 2001. In addition to computing the capacity estimates, we also illustrate how utilization of individual fisheries, total weeks of participation, and sizes of particular fleets have varied over the last decade. The specific data sources include Alaska Department of Fish and Game (ADFG) fish tickets, Federal blend data (which includes data from both observer reports and weekly production reports), ADFG vessel-registration files, and Federal vessel-registration files.

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ABSTRACT—Due to a lack of data on vessel costs, earnings, and input use, many of the capacity assessment models developed in the economics literature cannot be applied in U.S. fisheries. This incongruity between available data and model requirements underscores the need for developing applicable methodologies. This paper presents a means of assessing fishing capacity and utilization (for both vessels and fish stocks) with commonly available data, while avoiding some of the shortcomings associated with competing "frontier" approaches (such as data envelopment analysis).

[1]Thus, the capacity estimates reflect what could be caught in all Alaska commercial fisheries (state and Federally managed) by Federal fishery participants; the capacity of vessels that participated only in state fisheries was not estimated. As is the case in most fisheries, the capacity estimates are in terms of retained catch (not retained and discarded catch).

[2]The incentives that often give rise to over investment, and thus, excess capacity, are related to the restricted open-access management used in most fisheries and the associated race for fish (Kula, 1992).

[3]For example, one might want to know how much the existing fleet would catch, given existing stock levels, if all existing total allowable catch (TAC) limits were removed. Or, one might want to find the cost-minimizing or profit-maximizing level of catch associated with the existing fleet. There are several other capacity-related questions of interest, which, unfortunately, are often unanswerable given the existing data. The estimates computed here essentially reflect what could by caught by existing boats, with current technologies and stocks, if they fished the most number of weeks they have since 1990. An additional variant, allowing vessels to fish as much as their peers have in certain fisheries, is also provided. The following section provides more details.

Notions Underlying Capacity Measurement

In addition to the current fishing regulations, there are technological and economic constraints that limit the amount of fish that fishermen are willing and able to catch. Generally speaking, technological constraints can be thought of as "physical" limits on the maximum amount of fish that fishermen could catch (based on the gear used, the size and power of the vessel, the health of the stocks, weather, fishing skill, etc.). Economic constraints are those factors that affect fishermen's decisions over how much effort to exert and which species to catch (i.e. costs of fuel, bait, and labor; opportunity costs of participating in other fisheries; and ex-vessel prices).

Ideally, one could compute capacity measures that reflect the maximum amount of fish that could and would be caught by fishermen, given existing technological, biological, and economic constraints, if all regulatory restrictions governing catch were relaxed (NMFS, in press). Such measures would indicate the realistic "catching power" of the fleet,

and could then be compared to actual catch in order to gauge excess capacity (indicating the extent to which current production differs from an economically optimal level).

Similarly, one could compare existing capacity to some optimal, desired level of capacity at the current stock conditions or another reference point (such as when stocks are rebuilt to levels corresponding to maximum economic yield or maximum sustainable yield) to obtain a measure of overcapacity.[4]

Unfortunately, both endeavors require a great deal of information, most of which is lacking for Federally managed Alaska fisheries (as well as in most other fisheries); measurement of overcapacity requires the most information (and speculation) and is thus impractical for nearly all fisheries with current data collection practices. Notably, there is a general absence of data on production costs and input use (Felthoven, 2002).[5]

One approach that could be undertaken with the existing data is to construct "technical" capacity estimates using data envelopment analysis (DEA) or stochastic production frontier (SPF) models. Such analyses essentially focus on the maximum level of catch that vessels could obtain if they operated with full (and often heightened) technical efficiency and unrestricted use of variable inputs (Dupont et al., 2002). Typically, however, the maximum technical/physical level of catch exceeds that which would occur when economic factors (such as costs) are accounted for, and thus may overstate the amount that would be caught. For this reason, this paper does not derive technical capacity estimates. Rather, we attempt to purge the major constraints that limit fishing effort, while still accounting for the impacts of technological and economic constraints implicit in the data on catch and effort (another benefit of this approach is that we do not impute potential technical efficiency increases in the capacity estimates).

Put another way, the observed effort and catch histories for Alaska fisheries are a result of the regulatory, technical, and economic constraints that have typically existed. For example, catch levels reflect the relative prices paid for each target species, the technological tradeoffs of catching one species instead of another, and bycatch caps that limit the catch of prohibited species (which are joint in the production technology due to imperfect gear selectivity (Larson et al., 1998)).

The approach used to estimate current fishing capacity in this paper attempts to account for the decreases in effort, catch, and participation that have occurred over time due to decreases in the total allowable catch (TAC), which limit both catch and effort. While the capacity estimates still embody many of the spatial restrictions and bycatch constraints, they essentially reflect what would and could be caught by the fleet under normal operating conditions, given 2001 targeting strategies and the existing technical and economic constraints.

It is too complex a task to successfully mimic the removal of all existing regulatory constraints that limit catch, given the multitude of interactions and targeting strategies that arise in response to those regulations. In some cases, regulations for a species may generate direct regulatory and indirect economic impacts (such as area closures that force vessels to travel further out to sea) that can be very difficult to disentangle. For these reasons, no attempt is made to purge such effects in this study. Similarly, we do not speculate what could be caught under stock levels larger than those observed during 1990 to 2001. More detail on the exact procedures used in the process to estimate capacity will be provided later in the paper.

There are wide ranges of fishing activities, vessel sizes, targeting strategies, and gear configurations in the various Federally managed Alaska fisheries. Generally speaking, however, groups can be established that are likely to share similar technological, economic, and regulatory (TAC's, closures, seasonal delineation) constraints. In an attempt to establish such groups, vessel characteristics, fishery participation, and processing data (for catcher-processor vessels) were examined. As a result, 12 catcher vessel groups and 10 catcher-processor vessel groups were formed (hereafter referred to as "subgroups"). Each of these subgroups is comprised of similarly equipped and similarly sized vessels that engage in a common set of fisheries (in the case of catcher-processor vessels, they also produce a similar set of finished products). Such a grouping allows us to present the capacity estimates on a fleet-by-fleet basis, which more clearly elucidates the sources of fishing capacity.

In addition, by categorizing the vessels into homogeneous subgroups one has a more realistic idea of what vessels in each subgroup could have caught, even for those vessels that have exhibited very little activity. This in part allows one to account for latency in the capacity estimates, although we make no other attempt to account for latent capacity of inactive vessels in our estimates, as our focus is on active participants. However, one could easily estimate the capacity of the latent vessels with techniques similar to those illustrated here.

By focusing on the range of effort for a set of well defined, comparable peers, one can reasonably determine the effort levels that the less active vessels were capable of exerting (if economic incentives arose that led them to do so). Although care was taken defining and refining the 22 vessel subgroups designated in this paper, it is worth noting that the validity of these types of peer comparisons can be compromised by unobserved heterogeneity among vessels in each subgroup (FAO, 1998). For this reason, the estimator $\hat{C}_j^i$ avoids such comparisons (it is based solely on each vessel's historic participation) and should be interpreted as the more conservative capacity estimator. Alternatively, the estimator $\tilde{C}_j^i$ does involve comparisons among vessels within each subgroup, and thus it should

[4]National Marine Fisheries Service. 2001. Report of the Expert Group on Fish Harvesting Capacity. Final report to the National Oceanic and Atmospheric Administration, Contract #40-AA-NF-109717.

[5]One promising area where data availability may markedly improve is in the Bering Sea and Aleutian Islands crab fisheries. In March 2004, Congress approved a rationalization plan for these fisheries that included a mandatory data collection program. The program will collect vessel- and plant-level cost, earnings, and effort data. Therefore, it is likely that "economic" measures of capacity may be developed for these fisheries, which will aid in assessing the effects of the rationalization plan.

be interpreted more cautiously. Note, however, that in most cases the resulting estimates from the two estimators turned out to be quite similar, as illustrated by the tables at the end of this report. Further details on the estimators $\hat{C}_j^i$ and $\tilde{C}_j^i$ are given below.

Formulation of Capacity Estimators

There are several ways in which one could estimate the potential level of effort and catch of a fishing vessel, each of which could generate different estimates of capacity output. However, with the aim of providing realistic estimates of what could (and would) actually be caught, we base our analysis on each vessel's historical participation and effort in each of the Alaska commercial fisheries.

Specifically, we compare the total number of weeks each vessel fished in 2001 with the most weeks it fished over the 1990–2001 period (where 52 weeks is the greatest number of weeks each vessel could theoretically participate in a given year). If effort (in weeks) exceeded the 2001 effort in another year, it is assumed that the existing capacity of the vessel should be based upon that higher level of effort (which would instead be exerted upon the observed 2001 species composition). This process thus involves radially scaling up the observed 2001 catch statistics by the ratio of maximum operating weeks for 1990–2001 to observed operating weeks in 2001. This approach thus assumes constant returns to scale and Leontief input-output separability (Chambers, 1988).[6]

An issue that arises in basing the calculations on total annual effort is that one may generate participation levels in a specific fishery that are above any exhibited in the past. For example, if a vessel is now operating half as many total weeks as in a former year (and targets groundfish and crab), our approach would compute capacity as twice the size of the observed 2001 catch levels for groundfish and crab. If, however, groundfish effort had remained relatively stable over time and the drop in annual operating time was solely attributable to diminished crab participation, the implied increase in groundfish effort would be unrealistic.

We alleviate such potential problems by monitoring the total effort of each vessel within eight generally classified fisheries: groundfish (including walleye pollock, *Theragra chalcogramma;* Pacific cod, *Gadus macrocephalus*; Atka mackerel, *Pleurogrammus monopterygius;* rockfish, *Sebastolobus* and *Sebastes* species; sablefish, *Anoplopoma fimbria;* flatfish, primarily Alaska plaice, or *Pleuronectes quadrituberculatus;* and "other groundfish[7]"); Pacific herring, *Clupea pallasi;* Pacific halibut, *Hippoglossus stenolepis;* Pacific salmon, *Oncorhynchus* spp.; crab (including red king crab, *Paralithodes camtshaticus*; golden king crab, *Lithodes aequispinus;* and Tanner/snow crab[8], *Chionoecetes opilio* and *C. bairdi);* scallops, *Patinopectin caurinus;* "other shellfish[9]", and "other species[10]." If the implied potential increase in total annual effort implies a number of weeks in any particular fishery that exceeds the most weeks historically fished by that vessel in that fishery, the radial scaling of effort is then limited to take on that vessel's observed maximum for that fishery.

This first estimator will be denoted as $\hat{C}_j^i = \hat{\theta}_j^k Y_j^i$, where $\hat{C}_j^i$ is the capacity of vessel j for species i, $\hat{\theta}_j^k$ is a scaling factor for vessel j in fishery k, and Y_j^i is the observed output of vessel j for species i in 2001. The scaling factor $\hat{\theta}_j^k$ indicates the amount by which observed output could be increased, and is given by:

$$\hat{\theta}_j^k = \min\left\{\left(\frac{max.\ weeks_j}{weeks_j}\right), \left(\frac{max.\ weeks_j^k}{weeks_j^k}\right)\right\}.$$

Here, $max.\ weeks_j$ is the maximum number of weeks spent fishing by vessel j in any year for 1990–2001, $weeks_j$ is the observed number of weeks spent fishing by vessel j in 2001, $max.weeks_j^k$ is the maximum number of weeks spent fishing by vessel j in fishery k for 1990–2001, and $weeks_j^k$ is the number of weeks spent fishing by vessel j in fishery k for 2001. Note that θ_j^k is fishery-specific, not species-specific, and that each k^{th} fishery has a unique group of species i, i=1, … I. For example, the groundfish fishery includes seven species and the crab fishery includes four species (all other fisheries defined in this paper correspond to a single species or species "group").

If one broadens the scope of potential increases in an effort to incorporate information from a vessel's peers (i.e. their subgroup), a second, alternative capacity estimator can be generated. This estimator is formed by increasing each vessel's effort (in weeks) to its greatest historical level (as with the first estimator), subject to the constraint that the resulting implied number of weeks spent in each fishery does not exceed the most weeks in that fishery by any vessel in its subgroup for 1990–2001. This alternative formulation recognizes that the maximum historical weeks fished in a fishery by a vessel may not reflect the maximum level possible given the regulatory, technical, and economic constraints that are present. Rather, such a level may be better reflected by the maximum weeks fished in that fishery by another vessel in its subgroup. Thus, this second capacity estimator will generate estimates greater than or equal to the first estimator.

[6]Leontief output separability (i.e. that outputs move in fixed proportions) is also embodied in the capacity estimates generated by the commonly employed multi-output DEA and SPF capacity estimating models (FAO, 1998). Input separability assumes that the inputs used in fishing may be characterized by a composite variable such as days or weeks fished—common in the fisheries literature (Squires and Kirkley, 1991).

[7]This group includes yellowfin sole, *Limanda aspera;* Greenland turbot, *Reinhardtius hippoglossoides;* arrowtooth flounder, *Atheresthes stomias;* rock sole, *Lepidopsetta bilineata;* flathead sole, *Hippoglossoides ellassodon;* and Pacific Ocean perch, *Sebastes alutus*.

[8]Blue king crab, *Paralithodes platypus*, was also broken out as a separate category when analyzing production for the period of 1990 to 2001. However, because the vessels in this analysis caught no blue king crab in 2001, it is not represented in the capacity and capacity utilization estimates.

[9]This group is made up of clams, *Saxidomus giganteus, Spisula solidissima, Protothaca staminea;* shrimp, *Pandalus* spp.; abalone, *Haliotos kamtschatkana;* and other crab in the genus' *Lithodes, Paralithon*, and *Chionocetes*.

[10]This group is made up of lingcod, *Ophiodon elongates*; eels, genus *Anguilla*; and infrequently caught forage species.

The second capacity estimator will be denoted as $\tilde{C}_j^i = \tilde{\theta}_j^k Y_j^i$. The interpretation of the components of $\tilde{C}_j^i$ is the same as for $\hat{C}_j^i$, except that here, $\tilde{\theta}_j^k$ is defined as:

$$\tilde{\theta}_j^k = \min\left\{\left(\frac{max.\,weeks_j}{weeks_j}\right), \left(\frac{max.\,weeks^k}{weeks_j^k}\right)\right\}.$$

Thus, the ratio of

$$\frac{max.\,weeks_j^k}{weeks_j^k}$$

has been replaced with

$$\frac{max.\,weeks^k}{weeks_j^k}$$

where $max.weeks^k$ is the maximum number of weeks spent fishing by any of the vessels in this subgroup in fishery k for 1990–2001. Due to confidentiality requirements, and the sheer number of vessels involved in the fishery, this paper will present the values of

$$\hat{C}^i = \sum_{j=1}^{J} \hat{C}_j^i$$

and

$$\tilde{C}^i = \sum_{j=1}^{J} \tilde{C}_j^i$$

for each subgrouping of catcher vessels and catcher-processor vessels, where J= the number of vessels in each subgroup (the specific details of each subgroup are given below).

Formulation of Capacity Utilization and Fishery Utilization Measures

Typically, capacity utilization (CU) is defined as the ratio of observed output to capacity output (Morrison Paul, 1999). Following this convention, we will present two CU measures for each vessel subgroup, based on the $\hat{C}_j^i$ and $\tilde{C}_j^i$ capacity estimates for each species i. The first measure is defined as the ratio of observed catch by the vessel subgroup to capacity catch for the subgroup (where capacity is defined according to $\hat{C}_j^i$);

$$\hat{CU}^i = \left(\sum_{j=1}^{J} Y_j^i\right) \Big/ \left(\sum_{j=1}^{J} \hat{C}_j^i\right).$$

The second measure is defined as the ratio of total observed catch by the vessel subgroup to the second formulation of capacity catch for the subgroup:

$$\tilde{CU}^i = \left(\sum_{j=1}^{J} Y_j^i\right) \Big/ \left(\sum_{j=1}^{J} \tilde{C}_j^i\right).$$

Note that these aggregate subgroup-specific estimates of capacity utilization are in a sense catch-weighted, as vessels with a larger catch share of species i have a larger impact on the value of both $\hat{CU}^i$ and $\tilde{CU}^i$. It is worth noting again that these CU estimates embody the assumption that the 2001 catch composition for each vessel within each of the eight generally defined fisheries remains constant at capacity. Thus, the value of capacity for each species does not reflect what could or would be caught if all effort were exerted upon that particular species.

Rather, capacity (and the associated CU measures) for each species represents an estimate of what could be caught if all vessels increased their effort (according to the capacity estimators described above) and targeted their observed 2001 catch mix. This approach is thus more likely to generate realistic estimates of what could be caught within the bulk of Alaska fisheries by existing vessels.

Because the species-specific CU measures are not impacted by vessels that did not catch that particular species in 2001 (as both observed output and capacity output would be zero under our present methodology), they do not provide information on changes in annual participation. Instead, they indicate the intensity of effort, relative to past years, for those that are currently participating. Therefore, "fishery utilization" (FU) measures were constructed, which provide information on overall participation (in weeks), relative to past years, even in the absence of activity in a fishery in 2001.

These measures (FU_{Total}, $FU_{Groundfish}$, FU_{Salmon}, $FU_{Herring}$, $FU_{Halibut}$, $FU_{Scallop}$, FU_{Crab}, $FU_{Shellfish}$, $FU_{Other\ species}$) are simply defined as the ratio of weeks each vessel spent in each fishery in 2001 relative to the maximum ever observed for that vessel for 1990–2001 (averages are presented for each vessel subgroup). Note that FU_{Total} is the ratio of total weeks fished during the year in any activity in 2001 to the maximum number of total weeks fished during the year for 1990–2001. All other week-based FU measures reflect participation in individual fisheries (e.g. $FU_{Groundfish}$ is the ratio of the weeks a vessel spent in groundfish fisheries in 2001 to the most weeks it spent from 1990 to 2001 in groundfish fisheries). In summary, CU measures essentially represent vessel utilization by current fishery participants, while FU measures indicate the existing utilization of the fisheries, relative to past levels.

Measures of Capacity, Utilization, and Participation

The measures discussed and developed above will be presented in Tables 1 through 9 in various contexts. In some cases, measures will be expressed for the entire group of vessels in Federally managed Alaska fisheries, while in other cases the measures will focus on subsets (such as catcher-processor vessels, catcher vessels, or subgroups within each of these fleets). In order to fit the identifier for each catcher-processor vessel and catcher vessel subgroup in the tables below, abbreviated names, as developed for the environmental impact statements for Alaska groundfish fisheries, are used. The abbreviations used to identify each subgroup are defined as follows:

Catcher-Processor Vessels

ST-CP (surimi trawler catcher-processor): these factory trawlers have the necessary equipment to produce surimi from walleye pollock and other groundfish.

FT-CP (fillet trawler catcher-processor): these trawl vessels have the equipment to produce fillets (from

walleye pollock, Pacific cod, and other groundfish), and are not surimi-capable according to past production records.

HT-CP (headed and gutted trawler catcher-processor): these factory trawlers do not process more than incidental amounts of fillets. Generally, they are limited to headed and gutted products. In general, they do not focus their efforts on walleye pollock, opting instead for flatfish, rockfish, Pacific cod, and Atka mackerel.

P-CP (pot catcher-processor): these vessels have been used primarily in the crab fisheries of the North Pacific, but as of late they have increased their participation in the Pacific cod fisheries. They generally use pot gear, but may also use longline gear. They produce whole or headed and gutted groundfish products.

L-CP (longline catcher-processor): these vessels (also known as freezer longliners) do not trawl or use pot gear, and typically use longline gear to catch mostly Pacific cod. Most of these vessels are limited to headed and gutted products.

Salmon CP, Crab CP, Halibut CP, Other Shellfish CP: these groups are comprised of vessels that do not fit into the other catcher-processor categories above, and spend a large proportion of their fishery-weeks in salmon, crab, halibut, or "other shellfish" (those other than crab and scallops), respectively.

Other CP: these vessels do not fit into the other catcher-processor categories above, and did not spend a disproportionate number of weeks operating in the salmon, crab, or "other shellfish" fisheries (and thus weren't included in those subgroups).

All CP: this group includes all catcher-processors from the categories above, and is included to give overall measures for the catcher-processor sector.

Table 1.—Actual catch (t), capacity estimates, excess capacity, and week-based FU measures, by species, for catcher-processor and catcher vessels, 2001.[1]

Species	Actual catch	$\hat{C}$	Excess capacity (%)	$\tilde{C}$	Excess capacity (%)	Week-based FU
Atka mackerel	57,167	66,886	17.00	66,893	17.01	0.404
Flatfish	118,542	149,009	25.70	149,330	25.97	0.404
Pacific cod	227,532	306,976	34.92	318,117	39.81	0.404
Walleye pollock	1,449,333	2,010,866	38.74	2,030,470	40.10	0.404
Rockfish	26,559	32,208	21.27	32,595	22.73	0.404
Sablefish	15,101	18,691	23.77	20,137	33.35	0.404
Other groundfish	5,987	7,757	29.56	7,861	31.30	0.404
Pacific salmon	288,850	366,036	26.72	404,572	40.06	0.645
Pacific herring	33,654	42,656	26.75	46,240	37.40	0.196
Pacific halibut	27,176	31,587	16.23	40,023	47.27	0.426
Scallops	251	306	21.91	470	87.25	0.024
Golden king crab	3,006	6,608	119.83	7,018	133.47	0.278
Red king crab	3,963	15,037	279.43	15,909	301.44	0.278
Tanner crab	11,335	44,660	294.00	48,194	325.18	0.278
Other shellfish	468	528	12.82	576	23.08	0.252
Other species	1,571	1,710	8.80	2,144	36.46	0.258
All species	2,270,495	3,101,521	36.60	3,190,549	40.52	0.661

[1]The week-based FU measures are (unweighted) averages of the ratio of each vessel's 2001 weeks in that fishery to its maximum weeks in that fishery for 1990–2001. Thus, the FU measures for groundfish and crab are the same for each species classified in those fisheries. Note also that the week-based FU estimates for "All species" reflect the ratio of each vessel's total 2001 weeks fishing to its maximum historical weeks fishing, not an average of the week-based CU scores from each fishery.

Catcher Vessels

TCV BSP 125: all vessels for which trawl catch accounts for > 15% of total catch value, value of Bering Sea pollock catch is greater than value of catch of all other species combined, vessel length is ≥ 125 feet, and total value of groundfish catch is > $5,000. All vessels fishing after 1998 are AFA-eligible.

TCV BSP 60-124: all vessels for which trawl catch accounts for > 15% of total catch value, value of Bering Sea pollock catch is greater than value of catch of all other species combined, vessel length is 60–124 feet, and total value of groundfish catch is > $5,000. All vessels fishing after 1998 are AFA-eligible.

TCV Div. AFA: all vessels that are AFA-eligible for which trawl catch accounts for > 15% of total catch value, value of Bering Sea pollock catch is less than value of catch of all other species combined, vessel length is ≥ 60 feet, and total value of groundfish catch is > $5,000.

TCV Non AFA: all vessels that are not AFA-eligible for which trawl catch accounts for > 15% of total catch value, value of Bering Sea pollock catch is less than value of catch of all other species combined, vessel length is ≥ 60 feet, and total value of groundfish catch is > $5,000.

TCV < 60: all vessels for which trawl catch accounts for > 15% of total catch value, vessel length is < 60 feet, and total value of groundfish catch is > $2,500.

PCV: all vessels that are not trawl CV's for which the value of pot catch is > 15% of total catch value, vessel length is ≥ 60 feet, and total value of groundfish catch is > $5,000.

LCV: all vessels that are not trawl CV's or pot CV's for which vessel length is ≥ 60 feet, and total value of groundfish catch is > $2,000, excluding Pacific halibut and state-water sablefish.

FGCV 33-59: all vessels that are not trawl CV's for which vessel length is 33–59 feet, and total value of groundfish catch is > $2,000.

FGCV 32: all vessels that are not trawl CV's for which vessel length is ≤ 32 feet, and total value of groundfish catch is > $1,000.

Salmon CV, Crab CV: these groups are comprised of vessels that do not

Table 2.—Catcher-processor vessel capacity estimates.

Subgroup	Atka mackerel			Flatfish			Pacific cod		
	Actual	$\hat{C}$	$\tilde{C}$	Actual	$\hat{C}$	$\tilde{C}$	Actual	$\hat{C}$	$\tilde{C}$
ST-CP (n=13)	7,112	7,959	7,959	8,910	10,623	10,623	4,119	5,063	5,063
FT-CP (n=4)	—[1]	—	—	0.07	0.10	0.10	3,774	15,940	15,940
HT-CP (n=23)	49,827	58,571	58,571	93,144	117,102	117,102	25,749	32,922	32,922
P-CP (n=9)	7.90	17.6	21.5	220	284	330	7,888	10,669	11,412
L-CP (n=43)	135	139	141	2,557	2,783	2,791	107,305	130,258	130,923
Salmon CP (n=102)	—	—	—	—	—	—	0.95	2.18	2.18
Crab CP (n=15)	—	—	—	—	—	—	40.4	40.4	40.4
Halibut CP (n=22)	—	—	—	—	—	—	—	—	—
Other shellfish CP (n=9)	—	—	—	—	—	—	—	—	—
Other CP (n=6)	—	—	—	—	—	—	—	—	—
All CP (n=246)	57,082	66,688	66,693	104,831	130,793	130,848	148,877	194,896	196,304

Subgroup	Walleye pollock			Rockfish			Sablefish		
	Actual	$\hat{C}$	$\tilde{C}$	Actual	$\hat{C}$	$\tilde{C}$	Actual	$\hat{C}$	$\tilde{C}$
ST-CP (n=13)	506,153	692,768	692,768	1,993	2,243	2,243	35.5	40.7	40.7
FT-CP (n=4)	98,104	141,398	141,398	0.7	1.0	1.0	0.4	0.5	0.5
HT-CP (n=23)	16,827	20,989	20,989	15,652	18,496	18,496	802	1,078	1,078
P-CP (n=9)	130	145	165	0.35	0.39	0.44	8.6	28.1	35.4
L-CP (n=43)	4,901	6,196	6,215	236	278	279	1,754	2,026	2,034
Salmon CP (n=102)	—	—	—	—	—	—	—	—	—
Crab CP (n=15)	—	—	—	—	—	—	—	—	—
Halibut CP (n=22)	—	—	—	0.07	0.07	0.07	—	—	—
Other shellfish CP (n=9)	—	—	—	—	—	—	—	—	—
Other CP (n=6)	—	—	—	—	—	—	—	—	—
All CP (n=246)	626,116	861,497	861,536	17,882	21,018	21,019	2,602	3,175	3,189

Subgroup	Other groundfish			Pacific salmon			Pacific herring		
	Actual	$\hat{C}$	$\tilde{C}$	Actual	$\hat{C}$	$\tilde{C}$	Actual	$\hat{C}$	$\tilde{C}$
ST-CP (n=13)	651	935	935	—	—	—	—	—	—
FT-CP (n=4)	0.43	0.66	0.66	—	—	—	—	—	—
HT-CP (n=23)	637	734	734	—	—	—	—	—	—
P-CP (n=9)	5.2	9.8	9.9	0.36	0.36	0.66	—	—	—
L-CP (n=43)	1,980	2,416	2,417	—	—	—	—	—	—
Salmon CP (n=102)	—	—	—	4,182	4,818	5,297	719	738	738
Crab CP (n=15)	—	—	—	24.1	24.1	24.1	196	196	196
Halibut CP (n=22)	—	—	—	62.2	65.3	70.2	—	—	—
Other shellfish CP (n=9)	—	—	—	142.8	147.1	151.1	3.89	3.89	4.09
Other CP (n=6)	—	—	—	19.6	29.4	32.6	—	—	—
All CP (n=246)	3,274	4,096	4,096	4,432	5,085	5,577	919	937	938

Subgroup	Pacific halibut			Scallops			Golden king crab		
	Actual	$\hat{C}$	$\tilde{C}$	Actual	$\hat{C}$	$\tilde{C}$	Actual	$\hat{C}$	$\tilde{C}$
ST-CP (n=13)	—	—	—	—	—	—	—	—	—
FT-CP (n=4)	—	—	—	—	—	—	—	—	—
HT-CP (n=23)	—	—	—	—	—	—	—	—	—
P-CP (n=9)	—	—	—	—	—	—	—	—	—
L-CP (n=43)	284	315	337	—	—	—	—	—	—
Salmon CP (n=102)	177	187	206	—	—	—	—	—	—
Crab CP (n=15)	0.65	0.65	0.65	—	—	—	462	595	595
Halibut CP (n=22)	259	305	317	4.69	4.69	5.27	—	—	—
Other shellfish CP (n=9)	28.5	29.1	29.8	4.2	7.2	7.2	—	—	—
Other CP (n=6)	10.6	19.8	19.8	242.4	294.8	458.3	—	—	—
All CP (n=246)	761	858	912	251	306	470	462	595	595

Subgroup	Red king crab			Tanner crab			Other shellfish			Other species		
	Actual	$\hat{C}$	$\tilde{C}$	Actual	$\hat{C}$	$\tilde{C}$	Actual	$\hat{C}$	$\tilde{C}$	Actual	$\hat{C}$	$\tilde{C}$
ST-CP (n=13)	—	—	—	—	—	—	—	—	—	4.11	4.11	4.11
FT-CP (n=4)	—	—	—	—	—	—	—	—	—	—	—	—
HT-CP (n=23)	—	—	—	—	—	—	—	—	—	6.03	6.27	6.31
P-CP (n=9)	172	366	493	1,270	2,905	3,289	—	—	—	—	—	—
L-CP (n=43)	82.1	85.3	85.3	393	409	409	—	—	—	1.87	1.87	1.87
Salmon CP (n=102)	1.84	1.84	1.84	6.1	6.1	16.9	34.4	34.8	36.0	26.5	28.1	28.2
Crab CP (n=15)	155	209	240	220	667	783	0.69	0.80	0.80	—	—	—
Halibut CP (n=22)	1.05	1.05	1.05	11.98	11.98	11.98	8.7	8.7	11.3	0.80	0.82	0.90
Other shellfish CP (n=9)	—	—	—	0.67	0.67	1.12	58.2	58.9	70.9	16.5	17.7	17.7
Other CP (n=6)	32.9	51.3	51.3	58.5	91.1	91.1	—	—	—	1.34	1.59	2.00
All CP (n=246)	446	716	874	1,962	4,093	4,604	102	103	119	57.2	60.5	61.1

[1] "—" entries indicate that the subgroup did not catch any of that species in 2001.

Table 3.—Catcher vessel capacity estimates.

Subgroup	Atka mackerel			Flatfish			Pacific cod		
	Actual	$\hat{C}$	$\bar{C}$	Actual	$\hat{C}$	$\bar{C}$	Actual	$\hat{C}$	$\bar{C}$
TCV BSP 125 (n=30)	31.3	133.3	133.9	964	1,525	1,529	3,288	5,539	5,568
TCV BSP 60-124 (n=46)	32.6	43.4	44.1	887	1,253	1,282	8,126	11,058	11,503
TCV Div. AFA (n=29)	20.8	20.9	21.8	3,522	4,290	4,373	12,345	17,643	18,061
TCV Non-AFA (n=39)	—[1]	—	—	6,754	9,284	9,377	10,720	14,856	15,087
TCV < 60 (n=55)	—	—	—	930	1,132	1,164	10,348	12,566	13,366
PCV (n=162)	0.04	0.07	0.10	55.7	70.7	72.2	15,519	27,781	33,270
LCV (n=68)	0.01	0.01	0.01	57.3	58.6	60.4	726	772	774
FGCV 33-59 (n=939)	—	—	—	172	218	234	13,620	17,499	19,116
FGCV 32 (n=126)	—	—	—	5.2	18.4	22	853	1,086	1,177
Salmon CV (n=4,150)	—	—	—	5.6	5.6	5.6	404	405	459
Crab CV (n=49)	—	—	—	—	—	—	—	—	—
Other CV (n=993)	—	—	—	357.6	359	360	2,706	2,870	3,430
All CV (n=6,686)	85	198	200	13,711	18,216	18,482	78,655	112,080	121,813

Subgroup	Walleye pollock			Rockfish			Sablefish		
	Actual	$\hat{C}$	$\bar{C}$	Actual	$\hat{C}$	$\bar{C}$	Actual	$\hat{C}$	$\bar{C}$
TCV BSP 125 (n=30)	358,557	551,224	553,671	89.4	132.7	134.0	24.6	37.7	37.8
TCV BSP 60-124 (n=46)	349,945	443,702	456,194	478	573	576	31.9	39.1	39.3
TCV Div. AFA (n=29)	62,424	86,081	88,007	2,744	3,318	3,362	163	191	194
TCV Non-AFA (n=39)	25,479	36,042	36,720	3,602	4,913	4,941	237	326	328
TCV < 60 (n=55)	21,319	26,114	27,551	23.0	24.4	24.6	276	303	304
PCV (n=162)	2.6	4.2	5.3	39.6	60.6	64.1	606	825	845
LCV (n=68)	7.2	9.1	9.1	263	304	328	3,808	4,403	4,732
FGCV 33-59 (n=939)	159	263	278	1,069	1,446	1,651	6,994	8,986	10,010
FGCV 32 (n=126)	124	728	849	50.2	72.4	97.9	36.3	52.3	74.9
Salmon CV (n=4,150)	1,419	1,419	1,419	33.4	37.5	51.0	61.8	61.8	82.2
Crab CV (n=49)	—	—	—	0.09	0.09	0.2	—	—	—
Other CV (n=993)	3,781	3,781	4,230	284.5	307	345	259	289	298
All CV (n=6,686)	823,217	1,149,369	1,168,934	8,677	11,190	11,576	12,499	15,516	16,948

Subgroup	Other groundfish			Pacific salmon			Pacific herring		
	Actual	$\hat{C}$	$\bar{C}$	Actual	$\hat{C}$	$\bar{C}$	Actual	$\hat{C}$	$\bar{C}$
TCV BSP 125 (n=30)	1,076	1,545	1,556	31.5	31.5	41.4	59.3	63.5	73.4
TCV BSP 60-124 (n=46)	404	541	588	29.9	30.2	36.4	89.0	93.1	105.8
TCV Div. AFA (n=29)	545	678	691	19.2	20.3	26.9	43.1	50.5	52.6
TCV Non-AFA (n=39)	433	581	590	6.6	6.8	8.6	5.3	5.3	6.4
TCV < 60 (n=55)	70.0	86.1	89.3	10,338	11,516	13,620	612	673	787
PCV (n=162)	36.3	59.8	71.2	1.0	1.0	1.2	—	—	—
LCV (n=68)	23.8	25	25	42.7	50.1	135.7	55.9	166	221
FGCV 33-59 (n=939)	64.0	81.1	84.1	91,277	107,803	129,207	8,039	10,082	11,228
FGCV 32 (n=126)	0.6	1.0	2.17	1,428	2,176	2,717	103	183	219
Salmon CV (n=4,150)	3.7	3.8	4.2	159,708	212,021	223,693	20,539	26,516	28,597
Crab CV (n=49)	—	—	—	—	—	—	47.8	47.8	47.8
Other CV (n=993)	55.7	58.9	64.5	21,535	27,293	29,506	3,141	3,838	3,962
All CV (n=6,686)	2,713	3,661	3,765	284,418	360,951	398,995	32,735	41,719	45,302

Subgroup	Pacific halibut			Golden king crab			Red king crab		
	Actual	$\hat{C}$	$\bar{C}$	Actual	$\hat{C}$	$\bar{C}$	Actual	$\hat{C}$	$\bar{C}$
TCV BSP 125 (n=30)	40.7	40.7	48.0	—	—	—	92.0	125.7	148.5
TCV BSP 60-124 (n=46)	23.1	23.1	30.4	—	—	—	209	249	256
TCV Div. AFA (n=29)	144.5	144.5	196.7	—	—	—	43.8	135.0	135.0
TCV Non-AFA (n=39)	538	610	707	95.8	517.4	517.4	63.3	213.4	275.4
TCV < 60 (n=55)	622	672	765	—	—	—	2.7	3.5	3.5
PCV (n=162)	2,295	2,733	4,584	1,140	2,377	2,722	2,318	9,636	10,091
LCV (n=68)	5,541	5,987	6,879	49.0	140	140	47.3	108.8	108.8
FGCV 33-59 (n=939)	10,886	12,810	16,148	—	—	—	—	—	—
FGCV 32 (n=126)	825	974	1,223	—	—	—	—	—	—
Salmon CV (n=4,150)	961	1,154	1,367	—	—	—	—	—	—
Crab CV (n=49)	100	100	169	1,054	2,553	2,611	455	2,468	2,515
Other CV (n=993)	4,434	5,477	6,989	206	426	433	285	1,380	1,501
All CV (n=6,686)	26,415	30,729	39,111	2,544	6,013	6,423	3,517	14,321	15,035

Subgroup	Tanner crab			Other shellfish			Other species		
	Actual	$\hat{C}$	$\bar{C}$	Actual	$\hat{C}$	$\bar{C}$	Actual	$\hat{C}$	$\bar{C}$
TCV BSP 125 (n=30)	78.7	103.3	103.3	0.3	0.3	0.5	358	360	521
TCV BSP 60-124 (n=46)	155	192	196	—	—	—	432	440	552
TCV Div. AFA (n=29)	16.9	33.7	33.7	0.04	0.04	0.04	128	128	177
TCV Non-AFA (n=39)	86.9	434.3	496.6	0.01	0.01	0.01	113	114	147
TCV < 60 (n=55)	—	—	—	—	—	—	28.5	28.5	36.7
PCV (n=162)	7,015	29,429	32,220	—	—	—	5.0	5.2	7.7
LCV (n=68)	127	275	275	2.1	3.5	3.5	15.7	16.9	17.7
FGCV 33-59 (n=939)	—	—	—	183	204	229	181	223	267
FGCV 32 (n=126)	—	—	—	—	—	—	2.1	4.0	5.0
Salmon CV (n=4,150)	—	—	—	126	142	145	96	122	124
Crab CV (n=49)	1,198	6,066	6,162	—	—	—	—	—	—
Other CV (n=993)	694	4,032	4,102	53.7	75.2	78.8	155.1	208.7	229.6
All CV (n=6,686)	9,373	40,567	43,590	366	425	457	1,514	1,649	2,083

[1] "—" entries indicate that the subgroup did not catch any of that species in 2001.

Table 4.—Catcher-processor vessel catch-based capacity utilization estimates.

Subgroup	Atka mackerel		Flatfish		Pacific cod	
	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$
ST-CP (n=13)	0.894	0.894	0.839	0.839	0.814	0.814
FT-CP (n=4)	—[1]	—	0.700	0.700	0.237	0.237
HT-CP (n=23)	0.851	0.851	0.795	0.795	0.782	0.782
P-CP (n=9)	0.449	0.367	0.775	0.667	0.739	0.691
L-CP (n=43)	0.971	0.957	0.919	0.916	0.824	0.820
Salmon CP (n=102)	—	—	—	—	0.436	0.436
Crab CP (n=15)	—	—	—	—	1.000	1.000
Halibut CP (n=22)	—	—	—	—	—	—
Other shellfish CP (n=9)	—	—	—	—	—	—
Other CP (n=6)	—	—	—	—	—	—
All CP (n=246)	0.856	0.856	0.802	0.801	0.764	0.758

Subgroup	Walleye pollock		Rockfish		Sablefish	
	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$
ST-CP (n=13)	0.731	0.731	0.889	0.889	0.872	0.872
FT-CP (n=4)	0.694	0.694	0.700	0.700	0.800	0.800
HT-CP (n=23)	0.802	0.802	0.846	0.846	0.744	0.744
P-CP (n=9)	0.897	0.788	0.897	0.795	0.306	0.243
L-CP (n=43)	0.791	0.789	0.849	0.846	0.866	0.862
Salmon CP (n=102)	—	—	—	—	—	—
Crab CP (n=15)	—	—	—	—	—	—
Halibut CP (n=22)	—	—	1.000	1.000	—	—
Other shellfish CP (n=9)	—	—	—	—	—	—
Other CP (n=6)	—	—	—	—	—	—
All CP (n=246)	0.727	0.727	0.851	0.851	0.820	0.816

Subgroup	Other groundfish		Pacific salmon		Pacific herring	
	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$
ST-CP (n=13)	0.696	0.696	—	—	—	—
FT-CP (n=4)	0.652	0.652	—	—	—	—
HT-CP (n=23)	0.868	0.868	—	—	—	—
P-CP (n=9)	0.531	0.525	1.000	0.545	—	—
L-CP (n=43)	0.820	0.819	—	—	—	—
Salmon CP (n=102)	—	—	0.868	0.790	0.974	0.974
Crab CP (n=15)	—	—	1.000	1.000	1.000	1.000
Halibut CP (n=22)	—	—	0.953	0.886	—	—
Other shellfish CP (n=9)	—	—	0.971	0.945	1.000	0.951
Other CP (n=6)	—	—	0.667	0.601	—	—
All CP (n=246)	0.799	0.799	0.872	0.795	0.981	0.980

Subgroup	Pacific halibut		Scallop		Golden king	
	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$
ST-CP (n=13)	—	—	—	—	—	—
FT-CP (n=4)	—	—	—	—	—	—
HT-CP (n=23)	—	—	—	—	—	—
P-CP (n=9)	—	—	—	—	—	—
L-CP (n=43)	0.902	0.843	—	—	—	—
Salmon CP (n=102)	0.947	0.859	—	—	—	—
Crab CP (n=15)	1.000	1.000	—	—	0.776	0.776
Halibut CP (n=22)	0.849	0.817	1.000	0.890	—	—
Other shellfish CP (n=9)	0.979	0.956	0.583	0.583	—	—
Other CP (n=6)	0.535	0.535	0.822	0.529	—	—
All CP (n=246)	0.887	0.834	0.820	0.534	0.776	0.776

Subgroup	Red king		Tanner crab		Other shellfish		Other species	
	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$
ST-CP (n=13)	—	—	—	—	—	—	1.000	1.000
FT-CP (n=4)	—	—	—	—	—	—	—	—
HT-CP (n=23)	—	—	—	—	—	—	0.962	0.956
P-CP (n=9)	0.470	0.349	0.437	0.386	—	—	—	—
L-CP (n=43)	0.962	0.962	0.961	0.961	—	—	1.000	1.000
Salmon CP (n=102)	1.000	1.000	1.000	0.361	0.989	0.956	0.943	0.940
Crab CP (n=15)	0.742	0.646	0.330	0.281	0.863	0.863	—	—
Halibut CP (n=22)	1.000	1.000	1.000	1.000	1.000	0.770	0.976	0.889
Other shellfish CP (n=9)	—	—	1.000	0.598	0.988	0.821	0.932	0.932
Other CP (n=6)	0.641	0.641	0.642	0.642	—	—	0.843	0.670
All CP (n=246)	0.623	0.510	0.479	0.426	0.990	0.857	0.945	0.936

[1] "—" entries indicate that the subgroup did not catch any of that species in 2001.

fit into the other catcher vessel categories above and spend a majority of their fishery-weeks in salmon or crab, respectively.

Other CV: these vessels do not fit into the other catcher vessel categories above and did not spend a disproportionate number of weeks operating in the salmon or crab fisheries (and thus weren't included in those subgroups). These vessels tend to spend similar amounts of time landing salmon, herring, and various shellfish, albeit in small quantities.

All CV: this group includes all catcher vessels from the categories above and is included to give overall measures for the catcher vessel sector.

The actual catch and the associated capacity estimates (for both the $\hat{C}_j'$ and $\tilde{C}_j'$ estimators discussed above), by species, for all catcher-processor vessels and catcher vessels that operated in Federally managed Alaska fisheries in 2001 are presented in Table 1. Note that in all tables, the reported catch and capacity estimates are in metric tons. Furthermore, for brevity, common names are used in place of scientific names (or genus for groupings of similar species). Table 1 also reports the implied excess capacity (the difference between actual catch and catch levels corresponding to full capacity), and the week-based FU estimates. The estimates indicate that current capacity, in terms of total catch of all species, exceeds actual catch by nearly 40%. However, species-specific excess-capacity estimates range widely—from 8% to > 300%. Fishery utilization is highest in the salmon and groundfish fisheries and lowest in the shellfish and herring fisheries. Further breakdowns, into catcher vessel and catcher-processor vessel fleets (and subgroups within each), are provided in the following tables.

Capacity estimates for the catcher-processor vessel fleet as a whole, and for each subgroup, by species, are given in Table 2. Table 3 presents the capacity estimates for the catcher vessel fleet as a whole, and for each subgroup, by species. A majority of the capacity in the catcher-

processor vessel fleets is targeted toward pollock and Pacific cod, while most of the catcher vessel capacity is applied to pollock, salmon, and Pacific cod. As stated earlier, these estimates are based upon an assumed catch mix equal to that observed in 2001. Thus, for some species in Tables 2–5, the capacity estimate is given by a dash (-), which implies that no vessels in that subgroup caught that species in 2001.

CU estimates for the catcher-processor vessel fleet as a whole, and for each subgroup, by species, are contained in Table 4. Of all the primary target species, salmon and halibut targeting catcher-processor vessels have the highest levels of CU. Estimates of CU for catcher vessels in Table 5 reflect that CU is highest for halibut, sablefish, and salmon. It is interesting to note that both the halibut and sablefish fisheries operate under an Individual Transferable Quota (ITQ) system (which is often touted as a system that may decrease capacity in overcapitalized fisheries). Just as with the Tables 2 and 3, Tables 4 and 5 also have dashes for entries in cases where the specific subgroup did not catch any of that species in 2001. Note that the inverse of the CU scores (minus one) in Tables 4 and 5 yields an estimate of the percent by which capacity catch exceeds the actual catch observed in 2001.

Tables 6 and 7 present week-based FU estimates for the catcher-processor vessel and catcher vessel fleets (and their subgroups), respectively. Catcher-processor vessel FU is highest in groundfish and salmon fisheries, while salmon and halibut FU measures are the largest for catcher vessels. Entries with a dash in these tables imply that no members of that subgroup that fished in Federally managed fisheries in 2001 have participated in that specific fishery during 1990–2001. Entries with a zero imply that some vessels have participated in the past, but did not do so in 2001. The inverse of these FU scores (minus one) indicates the percent by which the vessels' annual participation in each fishery could increase, to match each vessel's historical maximum for the 1990–2001 period.

Finally, mean annual participation (in weeks) for the catcher-processor vessels

Table 5.—Catcher vessel catch-based capacity utilization estimates.

Subgroup	Atka mackerel		Flatfish		Pacific cod	
	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$
TCV BSP 125 (n=30)	0.235	0.234	0.632	0.630	0.594	0.591
TCV BSP 60-124 (n=46)	0.751	0.739	0.708	0.692	0.735	0.706
TCV Div. AFA (n=29)	0.995	0.954	0.821	0.805	0.700	0.684
TCV Non-AFA (n=39)	—[1]	—	0.727	0.720	0.722	0.711
TCV < 60 (n=55)	—	—	0.822	0.799	0.823	0.774
PCV (n=162)	0.571	0.400	0.788	0.771	0.559	0.466
LCV (n=68)	1.000	1.000	0.978	0.949	0.940	0.938
FGCV 33-59 (n=939)	—	—	0.789	0.735	0.778	0.712
FGCV 32 (n=126)	—	—	0.283	0.236	0.785	0.725
Salmon CV (n=4,150)	—	—	1.000	1.000	0.998	0.880
Crab CV (n=49)	—	—	—	—	—	—
Other CV (n=993)	—	—	0.996	0.993	0.943	0.789
All CV (n=6,686)	0.429	0.425	0.753	0.742	0.702	0.646

Subgroup	Walleye pollock		Rockfish		Sablefish	
	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$
TCV BSP 125 (n=30)	0.650	0.648	0.674	0.667	0.653	0.651
TCV BSP 60-124 (n=46)	0.789	0.767	0.834	0.830	0.816	0.812
TCV Div. AFA (n=29)	0.725	0.709	0.827	0.816	0.853	0.840
TCV Non-AFA (n=39)	0.707	0.694	0.733	0.729	0.727	0.723
TCV < 60 (n=55)	0.816	0.774	0.943	0.935	0.911	0.908
PCV (n=162)	0.619	0.491	0.653	0.618	0.735	0.717
LCV (n=68)	0.791	0.791	0.865	0.802	0.865	0.805
FGCV 33-59 (n=939)	0.605	0.572	0.739	0.647	0.778	0.699
FGCV 32 (n=126)	0.170	0.146	0.693	0.513	0.694	0.485
Salmon CV (n=4,150)	1.000	1.000	0.891	0.655	1.000	0.752
Crab CV (n=49)	—	—	1.000	0.450	—	—
Other CV (n=993)	1.000	0.894	0.927	0.825	0.896	0.869
All CV (n=6,686)	0.716	0.704	0.775	0.750	0.806	0.737

Subgroup	Other groundfish		Pacific salmon		Pacific herring	
	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$
TCV BSP 125 (n=30)	0.696	0.692	1.000	0.761	0.934	0.808
TCV BSP 60-124 (n=46)	0.747	0.687	0.990	0.821	0.956	0.841
TCV Div. AFA (n=29)	0.804	0.789	0.946	0.714	0.853	0.819
TCV Non-AFA (n=39)	0.745	0.734	0.971	0.767	1.000	0.828
TCV < 60 (n=55)	0.813	0.784	0.898	0.759	0.909	0.778
PCV (n=162)	0.607	0.510	1.000	0.833	—	—
LCV (n=68)	0.952	0.952	0.852	0.315	0.337	0.253
FGCV 33-59 (n=939)	0.789	0.761	0.847	0.706	0.797	0.716
FGCV 32 (n=126)	0.600	0.276	0.656	0.526	0.563	0.470
Salmon CV (n=4,150)	0.974	0.881	0.753	0.714	0.775	0.718
Crab CV (n=49)	—	—	—	—	1.000	1.000
Other CV (n=993)	0.946	0.864	0.789	0.730	0.818	0.793
All CV (n=6,686)	0.741	0.721	0.788	0.713	0.785	0.723

Subgroup	Pacific halibut		Golden king		Red king	
	CU	CU	CU	CU	CU	CU
TCV BSP 125 (n=30)	1.000	0.848	—	—	0.732	0.620
TCV BSP 60-124 (n=46)	1.000	0.760	—	—	0.839	0.816
TCV Div. AFA (n=29)	1.000	0.735	—	—	0.324	0.324
TCV Non-AFA (n=39)	0.882	0.761	0.185	0.185	0.297	0.230
TCV < 60 (n=55)	0.926	0.813	—	—	0.771	0.771
PCV (n=162)	0.840	0.501	0.480	0.419	0.241	0.230
LCV (n=68)	0.926	0.805	0.350	0.350	0.435	0.435
FGCV 33-59 (n=939)	0.850	0.674	—	—	—	—
FGCV 32 (n=126)	0.847	0.675	—	—	—	—
Salmon CV (n=4,150)	0.833	0.703	—	—	—	—
Crab CV (n=49)	1.000	0.592	0.413	0.404	0.184	0.181
Other CV (n=993)	0.810	0.634	0.484	0.476	0.207	0.190
All CV (n=6,686)	0.860	0.675	0.423	0.396	0.246	0.234

Subgroup	Tanner crab		Other shellfish		Other species	
	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$	$\hat{CU}$	$\tilde{CU}$
TCV BSP 125 (n=30)	0.762	0.762	1.000	0.600	0.994	0.687
TCV BSP 60-124 (n=46)	0.807	0.791	—	—	0.982	0.783
TCV Div. AFA (n=29)	0.501	0.501	1.000	1.000	1.000	0.723
TCV Non-AFA (n=39)	0.200	0.175	1.000	1.000	0.991	0.769
TCV < 60 (n=55)	—	—	—	—	1.000	0.777
PCV (n=162)	0.238	0.218	—	—	0.962	0.649
LCV (n=68)	0.462	0.462	0.600	0.600	0.929	0.887
FGCV 33-59 (n=939)	—	—	0.897	0.799	0.812	0.678
FGCV 32 (n=126)	—	—	—	—	0.525	0.420
Salmon CV (n=4,150)	—	—	0.887	0.869	0.787	0.774
Crab CV (n=49)	0.197	0.194	—	—	—	—
Other CV (n=993)	0.172	0.169	0.714	0.681	0.743	0.676
All CV (n=6,686)	0.231	0.215	0.861	0.801	0.918	0.727

[1] "—" entries indicate that the subgroup did not catch any of that species in 2001.

Table 6.—Mean catcher-processor vessel week-based fishery utilization measures.

Subgroup	FU_{Total}	$FU_{Groundfish}$	FU_{Salmon}	$FU_{Herring}$	$FU_{Halibut}$	$FU_{Scallop}$	FU_{Crab}	$FU_{Shellfish}$	$FU_{Other\ species}$
ST-CP (n=13)	0.759	0.759	0[1]	—[2]	—	—	—	—	0.500
FT-CP (n=4)	0.572	0.572	—	—	—	—	—	—	—
HT-CP (n=23)	0.760	0.759	0	—	—	—	—	0	0.300
P-CP (n=9)	0.462	0.470	1.000	—	—	—	0.183	0	—
L-CP (n=43)	0.814	0.802	0	—	0.388	—	0.071	—	0.143
Salmon CP (n=102)	0.856	0.002	0.902	0.559	0.592	—	0.500	0.836	0.421
Crab CP (n=15)	0.883	0.333	1.000	1.000	1.000	—	0.931	0.583	—
Halibut CP (n=22)	0.700	0.071	0.618	0	0.714	1.000	1.000	0.400	0.464
Other Shellfish CP (n=9)	0.834	0	0.642	1.000	0.666	0.166	0.666	0.925	0.300
Other CP (n=6)	0.711	0	0.222	—	0.200	0.813	0.300	—	0.438
All CP (n=246)	0.799	0.479	0.793	0.642	0.588	0.655	0.551	0.690	0.378

[1] Entries with a zero imply that some vessels have participated in the past, but did not do so in 2001.
[2] "—" entries indicate that the vessels in this subgroup have not participated in this fishery during 1990–2001.

Table 7.—Catcher vessel week-based fishery utilization measures.

Subgroup	FU_{Total}	$FU_{Groundfish}$	FU_{Salmon}	$FU_{Herring}$	$FU_{Halibut}$	$FU_{Scallop}$	FU_{Crab}	$FU_{Shellfish}$	$FU_{Other\ species}$
TCV BSP 125 (n=30)	0.616	0.620	1.000	0.809	1.000	—[1]	0.742	0.642	0.925
TCV BSP 60-124 (n=46)	0.761	0.775	0.944	0.667	0.974	—	0.269	0.270	0.952
TCV Div. AFA (n=29)	0.734	0.738	0.933	0.608	1.000	0[2]	0.340	0.545	0.847
TCV Non-AFA (n=39)	0.669	0.664	0.741	0.395	0.869	0	0.622	0.250	0.848
TCV < 60 (n=55)	0.742	0.629	0.740	0.304	0.596	—	0.100	0	0.632
PCV (n=162)	0.351	0.311	0.080	0	0.399	0	0.180	0	0.252
LCV (n=68)	0.717	0.700	0.190	0.333	0.768	0	0.083	0.240	0.296
FGCV 33-59 (n=939)	0.635	0.402	0.579	0.142	0.399	—	0	0.211	0.234
FGCV 32 (n=126)	0.527	0.285	0.460	0.073	0.393	—	0	0	0.169
Salmon CV (n=4150)	0.669	0.295	0.686	0.140	0.184	—	0.111	0.279	0.122
Crab CV (n=49)	0.446	0.125	0	0.119	0.636	—	0.470	0	—
Other CV (n=993)	0.688	0.426	0.425	0.202	0.618	—	0.261	0.212	0.267
All CV (n=6686)	0.657	0.402	0.640	0.182	0.421	0	0.269	0.238	0.254

[1] "—" entries indicate that the vessels in this subgroup have not participated in this fishery during 1990–2001.
[2] Entries with a zero imply that some vessels have participated in the past, but did not do so in 2001.

Table 8.—Mean annual catcher-processor vessel fishing weeks, 1990–2001.[1]

Subgroup	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
ST-CP	34.6	30.5	22.6	19.5	19.2	18.0	17.6	16.1	17.8	20.4	24.2	28.4
(No. of vessels)	(20)	(20)	(20)	(18)	(20)	(20)	(18)	(16)	(16)	(12)	(11)	(13)
FT-CP	39.9	37.1	34.4	26.8	24.6	22.5	21.8	19.2	20.3	21.5	22.0	24.5
(No. of vessels)	(17)	(18)	(18)	(22)	(15)	(13)	(14)	(13)	(12)	(4)	(4)	(4)
HT-CP	32.2	29.9	35.4	34.9	30.8	26.5	31.1	31.2	31.9	30.4	31.9	32.8
(No. of vessels)	(25)	(29)	(28)	(25)	(27)	(35)	(33)	(32)	(29)	(29)	(30)	(23)
P-CP	21.0	30.2	28.8	11.3	9.0	19.2	19.9	16.6	18.9	19.9	12.3	15.8
(No. of vessels)	(10)	(14)	(15)	(13)	(12)	(15)	(16)	(17)	(11)	(14)	(16)	(9)
L-CP	30.8	27.7	25.8	20.4	20.6	23.6	21.7	25.7	26.3	25.4	25.1	31.1
(No. of vessels)	(37)	(52)	(65)	(68)	(66)	(62)	(62)	(56)	(54)	(53)	(56)	(43)
Salmon CP	12.0	12.9	11.8	13.9	14.4	14.1	13.2	12.4	12.7	13.9	12.0	11.7
(No. of vessels)	(24)	(31)	(34)	(57)	(73)	(93)	(111)	(75)	(92)	(105)	(131)	(102)
Crab CP	30.3	27.4	25.1	14.8	11.9	10.6	7.9	12.5	12.4	10.8	11.2	7.7
(No. of vessels)	(12)	(14)	(14)	(10)	(7)	(5)	(8)	(12)	(13)	(14)	(5)	(15)
Halibut CP	—[2]	—	—	3.5	—	5.1	5.2	4.2	7.1	7.9	—	6.5
(No. of vessels)	(0)	(0)	(0)	(8)	(0)	(19)	(13)	(12)	(25)	(20)	(0)	(22)
Other shellfish CP	13.0	18.0	16.8	—	7.0	16.8	12.5	15.1	18.9	20.5	18.8	15.7
(No. of vessels)	(4)	(4)	(6)	(0)	(10)	(4)	(13)	(7)	(7)	(4)	(6)	(9)
Scallop CP[3]	—	—	15.8	9.0	—	1.7	—	7.3	6.2	5.0	—	—
(No. of vessels)	(0)	(0)	(4)	(6)	(0)	(6)	(0)	(4)	(5)	(7)	(0)	(0)
Other species CP[4]	—	—	—	9.5	—	8.6	10.8	—	—	—	—	—
(No. of vessels)	(0)	(0)	(0)	(4)	(0)	(5)	(4)	(0)	(0)	(0)	(0)	(0)
Other CP	8.8	5.3	8.3	10.6	6.0	6.4	6.0	9.3	10.8	17.8	8.5	7.0
(No. of vessels)	(4)	(6)	(4)	(5)	(5)	(5)	(5)	(4)	(6)	(5)	(8)	(6)
All CP	27.9	26.0	24.6	18.9	18.2	17.5	17.3	18.3	17.8	18.0	17.7	17.6
(No. of vessels)	(153)	(188)	(208)	(236)	(235)	(282)	(297)	(248)	(270)	(267)	(267)	(246)

[1] The mean weeks listed represents the time spent in Alaska commercial fisheries (state and Federal), for the species listed in this report, by vessels that fished in Alaska's Federally managed fisheries during 1990–2001.
[2] "—" entries indicate that the vessels in this subgroup did not participate in the Federally managed Alaska commercial fisheries in that year.
[3] This group, which was not defined for the 2001 capacity measures due to a lack of activity in 2001, is comprised of vessels whose predominant target was scallops.
[4] This group, which was not defined for the 2001 capacity measures due to a lack of activity, is comprised of vessels whose predominant targets were lingcod, eels, and infrequently caught forage species.

Table 9.—Mean annual catcher vessel fishing weeks, 1990–2001.[1]

Subgroup	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
TCV BSP 125	16.8	22.1	22.3	17.5	17.2	17.3	17.3	17.1	19.5	18.0	19.7	19.2
(No. of vessels)	(16)	(13)	(22)	(23)	(23)	(23)	(30)	(32)	(30)	(35)	(31)	(30)
TCV BSP 60-124	24.9	25.1	23.9	17.0	19.3	17.4	16.8	16.6	17.0	16.7	20.6	21.3
(No. of vessels)	(25)	(32)	(48)	(51)	(48)	(61)	(59)	(52)	(45)	(40)	(46)	(46)
TCV Div. AFA	25.3	26.5	23.0	25.1	21.9	22.1	23.7	24.4	22.3	20.5	20.1	21.7
(No. of vessels)	(34)	(47)	(31)	(30)	(27)	(22)	(19)	(25)	(32)	(33)	(29)	(29)
TCV Non-AFA	17.8	16.7	15.9	17.7	17.2	15.5	20.2	19.8	18.1	17.6	16.3	17.0
(No. of vessels)	(39)	(53)	(47)	(42)	(34)	(35)	(33)	(33)	(41)	(40)	(37)	(39)
TCV < 60	14.8	15.5	16.4	15.3	16.5	15.8	17.0	16.2	18.0	19.2	18.5	17.5
(No. of vessels)	(52)	(62)	(67)	(73)	(70)	(65)	(66)	(65)	(67)	(61)	(55)	(55)
PCV	11.3	14.0	14.9	11.8	8.3	10.8	11.8	11.2	12.8	12.7	9.8	6.9
(No. of vessels)	(160)	(178)	(177)	(170)	(173)	(154)	(163)	(143)	(151)	(161)	(177)	(162)
LCV	7.2	7.4	8.3	6.5	5.7	7.7	7.9	7.9	8.1	9.3	8.4	10.4
(No. of vessels)	(119)	(128)	(131)	(119)	(136)	(108)	(94)	(94)	(98)	(92)	(75)	(68)
FGCV 33-59	11.7	12.0	13.2	12.0	11.5	12.3	11.8	12.0	12.3	13.3	12.4	12.3
(No. of vessels)	(1,175)	(1,252)	(1,221)	(1,180)	(1,174)	(1,088)	(1,014)	(1,014)	(980)	(967)	(986)	(939)
FGCV 32	9.1	8.7	10.5	8.7	9.2	9.8	8.7	8.9	9.0	8.9	8.7	7.9
(No. of vessels)	(172)	(186)	(193)	(180)	(184)	(172)	(156)	(162)	(153)	(144)	(138)	(126)
Salmon CV	7.2	6.6	7.4	6.9	7.1	7.0	6.9	6.7	6.4	6.6	6.4	6.8
(No. of vessels)	(6,388)	(6,108)	(5,869)	(5,756)	(5,559)	(5,603)	(4,857)	(4,937)	(4,855)	(4,839)	(4,753)	(4,150)
Crab CV	10.4	10.8	12.1	9.9	5.8	6.5	5.4	7.2	9.2	7.9	4.5	4.6
(No. of vessels)	(49)	(49)	(47)	(59)	(67)	(72)	(61)	(46)	(36)	(37)	(44)	(49)
Scallop CV[2]	10.5	15.5	—[3]	10.0	3.6	—	—	—	—	—	—	—
(No. of vessels)	(4)	(4)	(0)	(4)	(5)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Other CV	5.2	5.1	5.3	5.8	5.3	7.1	6.8	7.1	7.7	7.6	7.3	7.2
(No. of vessels)	(1,849)	(1,881)	(1,762)	(1,443)	(1,433)	(1,112)	(1,154)	(1,176)	(996)	(1,069)	(657)	(993)
All CV	7.7	7.5	8.3	7.8	7.7	8.1	7.9	7.9	7.9	8.1	7.8	8.0
(No. of vessels)	(10,082)	(9,993)	(9,615)	(9,130)	(8,933)	(8,515)	(7,706)	(7,779)	(7,484)	(7,518)	(7,028)	(6,686)

[1] The mean weeks listed represents the time spent in Alaska commercial fisheries (state and Federal), for the species listed in this report, by vessels that fished in Alaska Federally managed fisheries during 1990–2001.

[2] This group, which was not defined for the 2001 capacity measures due to a lack of activity in 2001, is comprised of vessels whose primary target was scallops.

[3] "—" entries indicate that the vessels in this subgroup did not participate in the federally managed Alaska commercial fisheries in that year.

and catcher vessels for 1990 to 2001 is given in Tables 8 and 9, respectively. The tables also show the total number of vessels present in the fisheries discussed in this paper in each year (by subgroup and for the catcher-processor vessel and catcher vessel fleets as a whole). The average annual weeks fished by catcher-processor vessels has consistently dropped from its peak in 1990, which is due in part to the corresponding large increase in vessels since that time. The number of catcher vessels has dropped significantly since 1990, although average annual weeks fished has remained stable.

Conclusion

This paper presents a methodology for assessing fishing capacity, capacity utilization, and fishery utilization with commonly available data. The estimates provided in the paper allow analysts and resource managers to analyze capacity and utilization measures in two distinct ways, depending on the relevant questions at hand. Specifically, one can focus on well-defined subgroups (or "fleets") of vessels sharing similar harvesting and/or processing technologies, or examine the capacity and utilization measures by species.

This approach is easily implemented in large fisheries with multiple species and modes of operation and is not computationally burdensome. The assumptions underlying the estimates are similar to those embodied in alternative capacity estimation methodologies (such as DEA), but do not impute potential gains in harvesting efficiency in the resulting estimates. For these reasons, this methodology may be useful for those looking for a manageable and reasonable way to measure fishing capacity and resource utilization with existing data.

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Characteristics of Shark Bycatch Observed on Pelagic Longlines off the Southeastern United States, 1992–2000

LAWRENCE R. BEERKIRCHER, ENRIC CORTÉS, and MAHMOOD SHIVJI

ABSTRACT — Data collected by fisheries observers aboard U.S. pelagic longline vessels were examined to quantify and describe elasmobranch bycatch off the southeastern U.S. coast (lat. 22°–35°N, long. 71°–82°W). From 1992 to 2000, 961 individual longline hauls were observed, during which 4,612 elasmobranchs (15% of the total catch) were documented. Of the 22 elasmobranch species observed, silky sharks, Carcharhinus falciformis, *were numerically dominant (31.4% of the elasmobranch catch). The catch status of the animals (alive or dead) when the gear was retrieved varied widely depending on the species, with high mortalities seen for the commonly caught silky and night,* C. signatus, *sharks and low mortalities for rays (Dasyatidae and Mobulidae), blue,* Prionace glauca; *and tiger,* Galeocerdo cuvier; *sharks. Discard percentages also varied, ranging from low discards (27.6%) for shortfin mako,* Isurus oxyrinchus, *to high discards for blue (99.8%), tiger (98.5%), and rays (100%). Mean fork lengths indicated the majority of the observed bycatch — regardless of species — was immature, and significant quarterly variation in fork length was found for several species including silky; dusky,* C. obscurus; *night; scalloped hammerhead,* Sphyrna lewini; *oceanic whitetip,* C. longimanus; *and sandbar,* C. plumbeus; *sharks. While sex ratios overall were relatively even, blue, tiger, and scalloped hammerhead shark catches were heavily dominated by females. Bootstrap methods were used to generate yearly mean catch rates (catch per unit effort) and 95% confidence limits; catch rates were generally variable for most species, although regression analysis indicated significant trends for night, oceanic whitetip, and sandbar sharks. Analysis of variance indicated significant catch rate differences among quarters for silky, dusky, night, blue, oceanic whitetip, sandbar, and shortfin mako sharks.*

Introduction

In some commercial fishing operations, elasmobranchs represent a significant amount of discarded bycatch. Due to the slow growth rate, late maturity, and low fecundity of sharks in general, shark populations are particularly vulnerable to fishing pressure (Pratt and Casey, 1990). The history of directed shark fisheries in North American waters contains many examples of the deleterious effects overfishing can have on shark populations, including the rise and collapse of the porbeagle, *Lamna nasus* (Casey et al., 1978); soupfin shark, *Galeorhinus zyopterus* (Ripley, 1946); and spiny dogfish, *Squalus acanthias* (Rago et al., 1998) fisheries. Even in the case of species not subject to directed fisheries, such as many pelagic sharks, there is concern that bycatch mortality may still be high enough to harm shark populations (Musick et al., 2000). This concern has led to an urgent call for population assessments of elasmobranch species that often appear as bycatch in pelagic commercial fishing operations.[1]

To help increase the amount of management-relevant information available on pelagic sharks, we have examined nine years of fishery observer data to quantify and describe the patterns of shark bycatch in a major U.S. pelagic fishery, the swordfish, *Xiphias gladius*, and tuna, *Thunnus* spp., pelagic longline fleet, off the southeastern United States. These results may provide a clearer perspective of the magnitude of shark bycatch, and the distribution, relative abundance, and characteristics of shark populations that utilize the pelagic habitat in this region than has previously been available from fishery-independent scientific cruises alone. The data sources we used for this study, albeit fishery-dependent, offer the advantage of providing a much greater number of observations spread out over various times of the year from which to assess the status of Atlantic pelagic shark populations, and provide information relevant for their management.

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[1]NMFS. 2000. United States national plan of action for the conservation and management of sharks. U.S. Dep. Commer., NOAA, NMFS, Silver Spring, MD 20910, 86 p.

Materials and Methods

Description of the Fishery

The major fishery targeting large pelagic species off the southeastern United States is the pelagic longline fishery. Descriptions of this fishery can be found in Berkeley et al. (1981), Berkeley and

Campos (1988), and Beerkircher et al. (2002): the pelagic longline gear used in this area consists of a heavy monofilament mainline (7–65 km long), which is suspended at various depths below the surface and from which are suspended numerous lengths of lighter monofilament line with a single large (size 7/0–11/0) hook at the end. Hooks are placed along the line at a ratio of 11–19 hooks/km, resulting in a total of 80–1,200 hooks. The average number of hooks is 400–500 per longline. The gear free-floats on the surface of the ocean, with the hook depths varying from 35 to 60 m (Beerkircher et al., 2002).

Vessels targeting swordfish generally set gear around sunset and haulback around dawn, use chemical light sticks attached near the hooks, and use mackerel or squid for bait. Fishery-dependent data indicate an average of 4,028 longline sets were deployed per year in this area between 1994 and 1999 (Cramer, 1995; Cramer and Adams, 1999; Cramer, 2002). The primary species targeted by these fishermen is swordfish, although tunas, mahi-mahi, *Coryphaena* spp., and certain shark species are also commercially important portions of the catch.[2]

Bycatch in this fishery includes teleosts, elasmobranchs, and on rare occasions marine mammal and sea turtle species. The greatest percentage of bycatch in this fishery is composed of sharks (Anderson, 1985). Shark species commonly caught in the pelagic longline fishery include the dusky, *Carcharhinus obscurus*, night, *C. signatus*; silky, *C. falciformis*; oceanic whitetip, *C. longimanus*; tiger, *Galeocerdo cuvier*; blue, *Prionace glauca*; shortfin mako, *Isurus oxyrinchus*; and scalloped hammerhead, *Sphyrna lewini* (Anderson, 1985; Beerkircher et al., 2002).

Several of these species are neither generally described as "pelagic" in the literature nor defined as pelagic by the National Marine Fisheries Service (NMFS) Shark Fishery Management Plan (FMP).[2] Since several shark species encountered in the pelagic fishery occupy more than one habitat, this paper ignores subjective distribution classifications and describes bycatch of sharks of any species by the pelagic longline fishery off the southeastern United States.

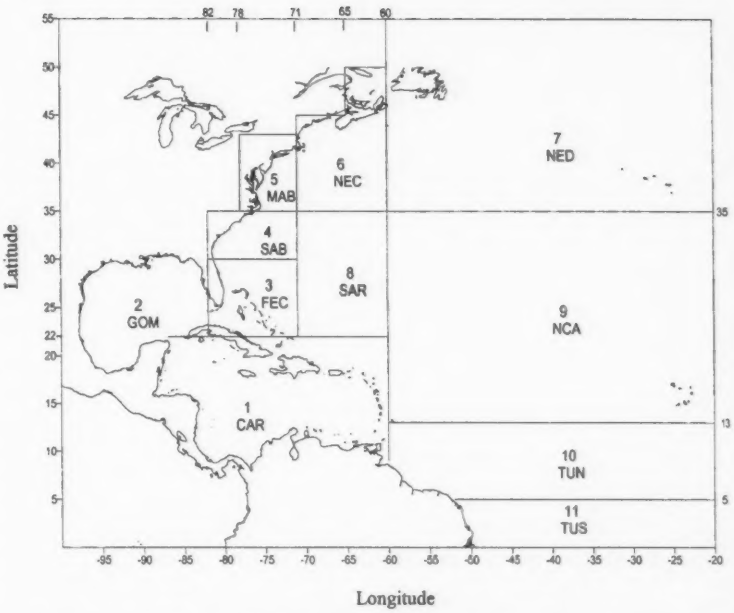

Figure 1. — NMFS geographical classification of fishing areas (Cramer and Adams, 1999). The study area combines NMFS areas 3 (FEC) and 4 (SAB).

Study Area and Data Set

The primary data we examined were compiled and maintained by the NMFS Southeast Fisheries Science Center (SEFSC) as part of the pelagic observer program and include data collected since the observer program's inception in June 1992 through December 2000. Observer coverage is mandatory for Federal swordfish permit holders, and selection of a vessel for coverage is based on a random draw. The percentage of longline sets observed in any given area and calendar quarter (quarter 1: January–March, quarter 2: April–June, quarter 3: July–September, quarter 4: October–December) was targeted to be 5% of the total reported number of sets for that area and calendar quarter in the previous year.

The northwest Atlantic (including the Gulf of Mexico and Caribbean) is divided into eleven areas thought to represent regions of similar types of fishing effort (Fig. 1). Two areas, the "Florida East Coast" (FEC, NMFS area 3) and the "South Atlantic Bight" (SAB, NMFS area 4) were combined into the study area examined herein. This area is bounded on the north and south by lat. 35° and 22°N and on the east and west by long. 71° and 82°W, respectively. This area was selected as the spatial limits of the study because the pelagic longline fishery in it has been classified as one of the five distinct U.S. Atlantic pelagic longline fisheries based on the nature of the target species, temporal distribution of effort, and other fishing practices.[2] The rough similarity of fishing effort throughout this area allows some standardization of catch per unit of effort (CPUE) data, which would be more difficult if a larger study area encompassing variable fishing practices were used. One observed shark-directed set that occurred in shallow water during 1996 was not included in the analysis to preserve

[2]NMFS. 1999. Final fishery management plan for Atlantic tunas, swordfish, and sharks. U.S. Dep. Commer., NOAA, NMFS, Silver Spring, MD 20910, 854 p.

Table 1.—Observed and reported effort in the pelagic longline fishery off the southeastern U.S., 1992–2000.

Effort	Year									Total
	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Observed effort										
Hauls	72	129	119	67	126	95	116	111	126	961
Hooks	19,315	47,846	38,126	25,184	61,943	48,778	49,214	54,338	69,129	413,873
Reported effort[1]										
Hooks	1,094,082	1,281,618	1,516,723	1,496,686	2,249,194	1,677,461	1,357,197	1,474,411	1,484,554	13,631,926
Percent of hooks observed	1.8	3.7	2.5	1.7	2.8	2.9	3.6	3.7	4.7	3.0

[1] Data from Cramer, 1995; Cramer and Adams, 1999; and Cramer, 2002.

Table 2.—Cumulative monthy effort and elasmobranch catch by species observed in the pelagic longline fishery off the southeastern U.S., 1992–2000.

Species	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	%
Silky	55	159	184	163	255	120	81	63	81	137	81	67	1,446	31.4
Dusky	5	15	107	39	125	186	28	49	58	34	27	6	679	14.7
Night	1	39	128	153	160	52	7	15	0	11	4	2	572	12.4
Blue	4	63	67	102	115	52	2	2	0	6	8	13	434	9.4
Unidentified sharks	9	11	21	39	29	83	9	35	7	19	11	34	307	6.7
Tiger	5	25	4	42	46	20	22	22	17	26	16	18	263	5.7
Scalloped hammerhead	5	22	10	4	29	46	10	13	16	13	7	25	200	4.3
Oceanic whitetip	1	8	3	8	12	5	7	11	12	24	25	15	131	2.8
Rays	0	12	12	9	4	1	5	16	13	9	18	14	113	2.5
Sandbar	1	6	7	7	20	48	16	3	0	0	2	2	112	2.4
Bigeye thresher	1	2	10	10	13	12	11	4	3	3	2	11	82	1.8
Shortfin mako	3	13	11	3	15	11	2	8	1	3	2	8	80	1.7
Other[1]	14	11	22	19	26	49	9	2	4	21	7	9	193	4.2
Totals	104	386	586	598	849	685	209	243	212	306	210	224	4,612	
Hooks	7,796	38,128	37,275	57,835	62,247	71,395	22,136	27,221	15,793	27,491	21,897	24,659	413,873	

[1] Other includes (in numerical order) great hammerhead, *Sphyrna mokarran*; bignose, *Carcharhinus altimus*; blacktip, *C. limbatus*; longfin mako, *Isurus paucus*; bull, *C. leucas*; common thresher, *Alopias vulpinus*; spinner, *C. brevipinna*; Caribbean reef, *C. perezi*; smooth hammerhead, *S. zygaena*; and nurse, *Ginglymostoma cirratum*, sharks.

CPUE standardization and the intent of the study to examine shark bycatch in the tuna-swordfish fishery.

Quantitative Methods Used for Data Analysis

Bootstrap procedures with 1,000 bootstrap replications (Efron and Tibshirani, 1993) were used to estimate the mean yearly CPUE (expressed as number of sharks caught per 1,000 hooks) for eleven commonly observed elasmobranch species and for unidentified sharks as a group. Upper and lower 95% confidence limits were taken from the 97.5 and 2.5 percentiles of the ranked replicant means, respectively.

For each shark species, mean CPUE was analyzed to test for differences among seasons using analysis of variance (ANOVA); post-hoc identification of seasonal differences were determined by Tukey-Kramer testing (Sokal and Rohlf, 1995). Yearly time series of bootstrapped mean CPUE were charted; yearly mean CPUE values were weighted by the inverse of the yearly bootstrapped variance and both weighted and non-weighted CPUE series were analyzed for significant trends through linear regression.

Live sharks that are not retained (due to quota closures, small size, or low commercial value) are normally cut off the line in the water, and precise length measurements are therefore not possible. In such cases, the observer estimates the total length of the shark to the nearest foot. Because exclusion of estimated length data would preclude length analyses for species such as the blue; tiger; scalloped hammerhead; oceanic whitetip; sandbar, *C. plumbeus*; bigeye thresher, *Alopias superciliosus*; and shortfin mako, we included estimated lengths for these species in our analyses. Fork length was chosen for analysis because this is the most consistently reported measurement by observers. Fork length data were log-transformed and analyzed using one-way ANOVA and Tukey-Kramer testing to determine if and where length differences existed among seasons. Length-frequency distributions were constructed for the four most-common species observed; mean fork lengths were calculated for the ten most-common shark species observed.

Sex ratios over the entire study period were determined for most species (rarely encountered species or species for which sex data were lacking, were omitted). To detect any seasonal changes in sex ratios, quarterly sex ratios were examined for ten of the most common species. Chi-square testing was used to analyze the sex ratio data for heterogeneity among quarters.

Results and Discussion

General

During June 1992 through December 2000, NMFS personnel observed 961 individual hauls of longline fishing gear in the study area (Table 1). Mean yearly observed effort was 107 hauls and 45,986 hooks. The greatest amount of yearly effort was observed in 2000 (69,129 hooks), and the minimum in a 7-month period in 1992 (19,315 hooks). Monthly fishing effort ranged from a high of 71,395 hooks observed in June to a low of 7,796 hooks in January (Table 2). Observations of the fishing effort were distributed uniformly throughout the time period of the study, occurring in all

seasons of all years, except for 1992. This was the year when the observer program began at the SEFSC, and field operations did not start until June. The locations of individual hauls of the gear (by quarter) are shown in Figure 2.

Spatially, the fishing effort was generally confined to the Gulf Stream or its edges, in water depths greater than 200 m. Thus, although the defined study area includes the Bahamas, very little effort was observed in the immediate vicinity of the Bahamas due to a restriction on U.S. longliners operating in the Bahamian Exclusive Economic Zone (EEZ). An exception was the Florida Straits, where the close proximity of the Bahamian islands to the continental United States results in a narrower EEZ for both countries.

Elasmobranchs comprised 15% and the target species (swordfish and tuna) comprised 53% of the total catch (Fig. 3). A total of 4,612 individual elasmobranchs were observed during the study period, with silky, dusky, night, blue, unidentified, tiger, and scalloped hammerhead sharks making up the majority (84.6%); 15 other species made up the remainder of the elasmobranchs observed (Table 2). Rays were not identified to species, but observer notes indicate the majority were pelagic stingrays, *Dasyatis violacea*; and some manta rays (Mobulidae) were also reported. The wide variety of species observed in the study was consistent with the temporal and spatial distribution of fishing effort and a previous study on pelagic zone sharks in the same general region (Berkeley and Campos, 1988).

The intent of our study was to identify the characteristics of that portion of the shark populations that use the pelagic zone (>200 m), although due to the free-floating nature of pelagic longline gear some of the effort observed might have come from water as shallow as 100 m. A review of the gear haul location data indicated that few sets of gear drifted into shallower water. Therefore, it seems reasonable to assume the species diversity observed is fairly representative (within the constraints of the nature of the fishing gear) of elasmobranchs that use the pelagic zone in this region, and particularly those species that frequent the Gulf Stream and its edges.

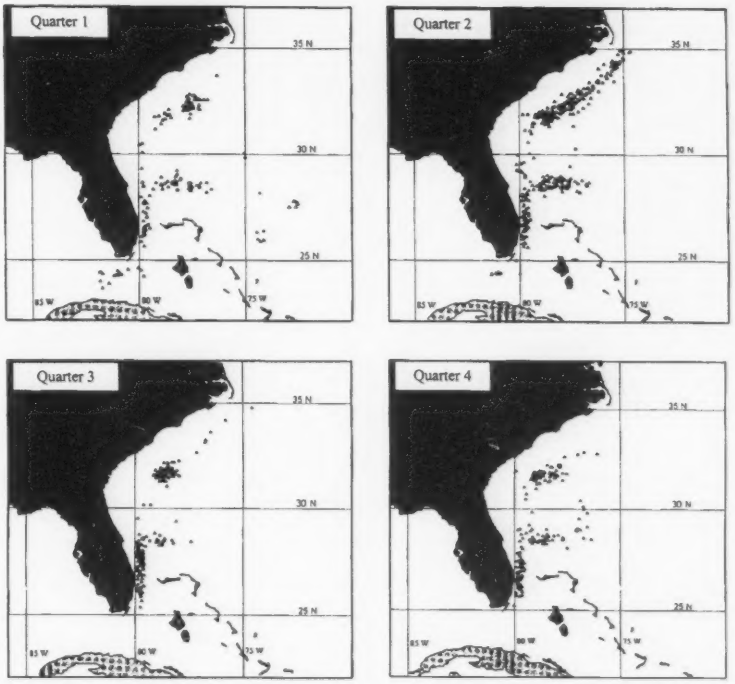

Figure 2. — Locations of observed hauls in the pelagic longline fishery off the southeastern U.S. coast, 1992–2000, by quarter.

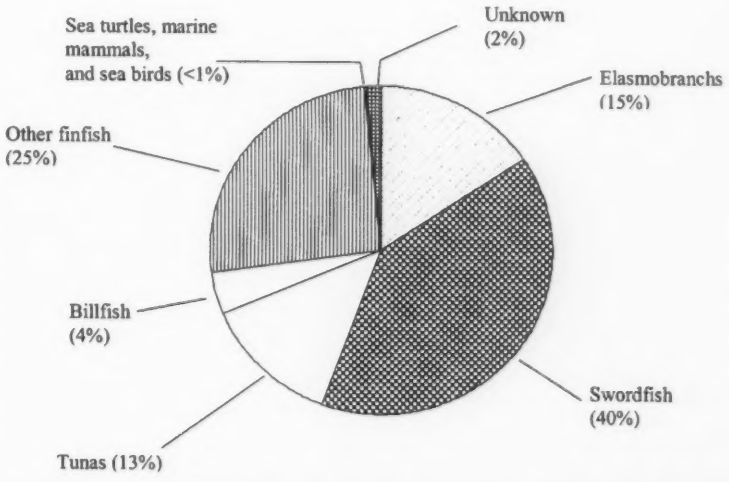

Figure 3. — Percentage of observed catch by category from the pelagic longline fishery off the southeastern U.S. coast, 1992–2000.

The numerical dominance of the silky shark in elasmobranch bycatch observed in this study agrees with similar studies that document this species as making up a large portion of the longline shark bycatch off the southeastern U.S. coast (Guitart-Manday, 1975; Hoey, 1983a; Berkeley and Campos, 1988). However, the relatively high percentage of shark bycatch comprising dusky sharks (14.7%) is not typical of previous findings. Hoey (1983a) found this species to comprise only 5.8% of the total shark catch off the southeastern U.S. coast, although this data set was hampered by species identification problems, and many of the unidentified sharks reported in Hoey's study may have been dusky sharks. Further, Hoey's (1983a) data were dominated by shark-directed effort, which presumably occurred in more shallow water.

Two NMFS bottom longline, fishery-independent shark surveys captured only three dusky sharks in water depths less than 80 m along the coast from Cape Cod, Mass., to Texas (Grace and Henwood, 1997). Springer (1963) reported the dusky shark as being common off the coast of Florida in relatively deeper waters (60–300 m); however, other researchers who have examined catch data from the southern portion of the study area have not found the dusky shark to be as common offshore as we report here (Guitart-Manday, 1975; Berkeley and Campos, 1988).

The night shark, the third-most common elasmobranch observed in our study (12.4%), has also been reported as common in the study area by previous authors, particularly in the Florida Straits (Guitart-Manday, 1975; Castro, 1983; Berkeley and Campos, 1988). The amount of night sharks we observed in the study area is inconsistent with information presented in Castro et al. (1999), who reported night sharks as being rare off the southeastern United States.

In our study, NMFS observers reported very few night sharks in the first 4 years (1992–95), but many more from 1996 to 2000. Unless there was some change in fishing effort after 1996, or a major change in the population's size or migratory patterns in those years — both of which seem doubtful — NMFS observers either misidentified night sharks or reported them as "unidentified sharks" during the early years of the SEFSC pelagic longline observer program.

It seems likely that more night sharks were caught during 1992–95 but were reported mostly as "unidentified sharks" by NMFS observers. Unfortunately, it is also probable that some night sharks were misidentified as other species in the genus *Carcharhinus*. Despite the uncertainty of accurate species identification, our data suggest that the night shark is still a relatively common species in the study area, although a decline in abundance from historical levels is possible.

Table 3.—Catch status of elasmobranchs observed in the pelagic longline fishery off the southeastern U.S., 1992–2000.

Species	Alive	Dead	Unknown	Damaged	% Dead
Silky	487	949	0	10	66.3
Dusky	348	325	0	6	48.7
Night	110	451	0	11	80.8
Blue	381	49	0	4	12.2
Tiger	255	8	0	0	3.0
Scalloped hammerhead	77	117	1	5	61.0
Oceanic whitetip	95	36	0	0	27.5
Rays	113	0	0	0	0.0
Sandbar	82	29	0	1	26.8
Bigeye thresher	38	43	0	1	53.7
Shortfin mako	52	28	0	0	35.0

Catch Status and Disposition

The catch status (condition of the animal, defined as dead or alive, when brought alongside the boat) varied widely depending on species (Table 3). Rays, tiger sharks, and blue sharks were observed to survive best (0%, 3.0%, and 12.2% mortality, respectively), but the three most common shark species in the study — silky, dusky, and night — had much higher mortalities (66.3%, 48.7%, and 80.8%, respectively).

These mortality data suggest that catch status should be taken into account when considering species-specific management measures, as prohibitions on possession of species with generally low survival rates may not substantially reduce bycatch mortality, but might have the effect of reducing economic benefits to the fishermen. Detailed and more extensive examination of fishery-dependent data with concomitant research on gear modification will be necessary for development of regulations aimed at increasing the number of sharks that survive capture.

Table 4.—Catch disposition of elasmobranchs observed in the pelagic longline fishery off the southeastern U.S., 1992–2000.

Species	Retained (%)	Discarded dead (%)	Released alive (%)
Silky	30.0	44.1	25.9
Dusky	24.6	38.7	36.7
Night	26.0	61.9	12.1
Blue	0.2	12.4	87.3
Tiger	1.5	4.6	93.9
Scalloped hammerhead	14.1	51.8	34.2
Oceanic whitetip	24.4	14.5	61.1
Rays	0.0	4.4	95.6
Sandbar	23.2	19.6	57.1
Bigeye thresher	15.9	43.9	40.2
Shortfin mako	72.4	0.0	27.6

The percentage distribution of catch disposition (i.e. whether the elasmobranch was kept, released alive, or released dead) was also highly variable, ranging from 72.4% kept for shortfin mako to less than 2% kept for blue sharks, tiger sharks, and rays (Table 4). The catch disposition percentages we report are likely the result of a combination of factors such as marketability of the species and compliance with fishery regulations. Several of the most common species observed in this study are subject to quota closures, and thus a significant portion of the discard figures for these species might be regulatory.

Length Characteristics

Mean fork lengths by gender (Table 5) were calculated from both actual measurements and combined actual and estimated measurements, with the exception of blue, tiger, and bigeye thresher sharks, for which virtually all lengths were estimated. Because large sharks that fishermen do not intend to keep are rarely

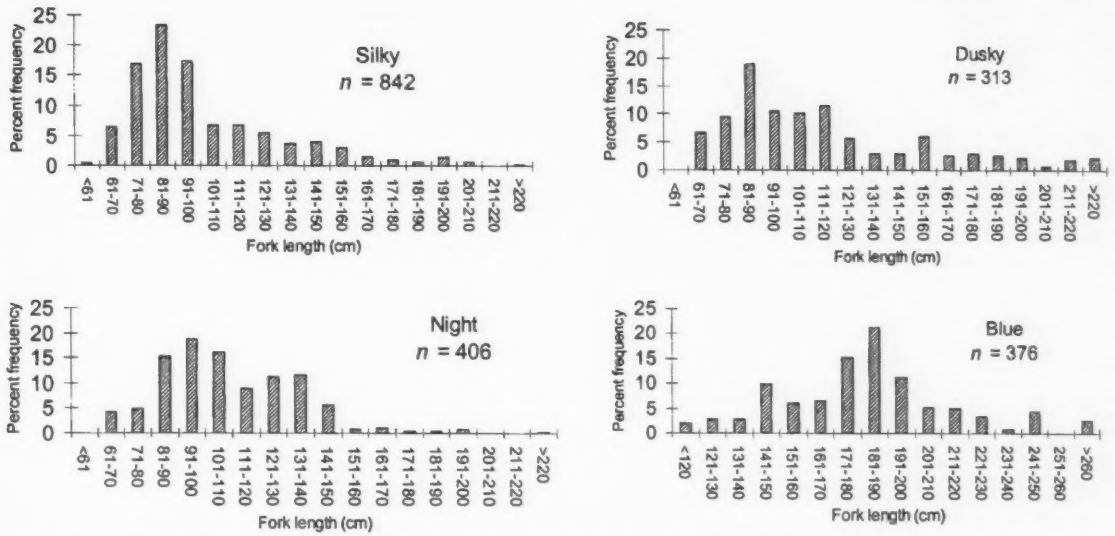

Figure 4. — Percent length-frequency distributions observed for silky, dusky, night, and blue sharks off the southeastern U.S. coast, 1992–2000. All length data were from actual measurements except for blue sharks, where 97% of the length data were estimations.

Table 5.—Mean fork lengths (FL) of sharks observed in the pelagic longline fishery off the southeastern U.S., 1992–2000. Length-at-maturity estimates are taken from the literature cited here; estimates are given as length at first maturity or a range according to the the original study. Where sources reported total length, conversions to fork length were made using relationships given in Kohler et al. (1995).

		Actual measurements (cm)		All measurements (cm)			
Species	Sex	*n*	FL	*n*	FL	Length at maturity (cm)	Citation
Silky	M[1]	375	103	440	107	186	Bonfil et al., 1993
	F[1]	461	101	591	107	192–203	
Dusky	M[1]	163	117	224	119	231	Natanson et al., 1995
	F[1]	148	116	220	125	235	
Night	M[1]	222	109	243	111	156–160	Hazin et al., 2000
	F[1]	181	109	212	113	168–173	
Blue	M	N/A[2]	N/A	22	198	183	Pratt, 1979
	F	N/A	N/A	58	189	185	
Tiger	M[1]	N/A	N/A	21	211	258	Branstetter et al., 1987
	F[1]	N/A	N/A	47	198	263–267	
Scalloped hammerhead	M	24	150	43	156	139	Branstetter et al., 1987
	F[1]	34	146	71	173	194	
Oceanic whitetip	M[1]	24	105	34	100	145–153	Lessa et al., 1999
	F[1]	27	105	44	100	145–153	
Sandbar	M[1]	26	142	36	149	150	Sminkey and Musick, 1995
	F	10	145	19	156	150	
Bigeye thresher	M	N/A	N/A	21	192	172	Moreno and Morón, 1992
	F[1]	N/A	N/A	16	190	208	
Shortfin mako	M	38	186	39	186	179	Stevens, 1983
	F[1]	21	177	22	175	258	

[1] Indicates species/gender whose mean lengths were below reported maturity size.
[2] N/A = not available.

brought aboard for actual measurement by observers, using only actual measurements to determine mean fork lengths might result in smaller mean sizes being estimated than those actually occurring in the fishery.

For most of the species, mean fork lengths estimated from the combined data were greater than those obtained from actual measurements only. Even then, mean lengths were still clearly below the reported size at maturity (for both males and females) in silky, dusky, night, tiger, and oceanic whitetip sharks. For the three most common species (silky, dusky, and night sharks) greater than 95% of the observed catch consisted of immature individuals (Fig. 4).

Gear selectivity should be considered when examining length data derived from longline observation. The gear type used by U.S. pelagic longline fishermen consists largely of monofilament. Although many authors have reported length infor-

mation from sharks taken by monofilament longline gear, few have discussed the possibility that the mean lengths and length frequencies constructed from catch data may not be representative of the actual length characteristics of the population.

Hoey (1983b) believed that most "lost hooks" or "bite offs" (a gangion that is retrieved without the hook, the monofilament having been broken or cut in some way) were a result of sharks taking the bait, and all such incidences were recorded in his data as "unidentified sharks." Because it seems reasonable to assume that larger and stronger sharks would stand a greater chance of severing the monofilament gangion, the observed catch data could be biased in favor of smaller sharks.

Berkeley and Campos (1988) provided the only evidence available that the size and characteristics of sharks are not influenced by the use of monofilament gangions. These authors used steel gangions for 20–25% of the hooks set during the first 13 sets of their 111-set study and found no significant differences in either the species composition or the mean size of the shark catch between the two gangion types.

We suggest, however, that given the common occurrence of gangion "bite offs", it is likely that size selectivity is occurring in the fishery. Such selectivity should be detected by analysis of catches from gangions of various strengths. Preliminary comparisons of the observed size of silky sharks captured on gangions of two different breaking strengths, 135 kg (300-lb) test and 180 kg (400-lb) test, have shown that significantly larger silky sharks were observed on gear utilizing the stronger gangions (Beerkircher[3]). The relationship between catch lengths and gangion size should be explored further as it may have important implications when examining long-term changes in catch size distributions.

ANOVA results indicate significant fork length differences among quarters for silky (F=6.51; df=3, 839; P<0.0001), dusky (F=7.55; df=3, 309; P<0.0001), night, (F=8.34; df=3, 402; P<0.0001), oceanic whitetip (F=9.00; df=3, 111; P<0.0001), and sandbar (F=4.61; df=3, 93; P<0.0047) sharks. Post-hoc tests on silky, dusky, and sandbar sharks indicated that significantly smaller individuals were observed during the fourth quarter (October–December) compared to the rest of the year.

For the silky shark, these data, coupled with the length-frequency results (Fig. 4) indicating that few silky sharks at or below the reported size of neonates (60 cm or less; Bonfil et al., 1993) were observed in the study area, are consistent with Springer's (1967) hypothesis that silky shark neonates may stay near reefs on the outer shelf until they have grown large enough to move to pelagic habitats. This movement probably occurs by the first winter after a late spring–early summer pupping season (Branstetter, 1987). The quarterly ANOVA result of a smaller mean size observed in quarter 4 could reflect the yearly movement of small young-of-the-year silky sharks into the pelagic habitat.

Table 6.—Regression results of mean yearly CPUE series for sharks observed in the pelagic longline fishery off the southeastern U.S., 1992–2000. Only species with statistically significant results ($P < 0.05$) are shown. SE=standard error.

Species	Series type	R^2	Slope	SE of slope	P
Night	Variance-weighted	0.592	–3.782	1.188	0.015
	Non-weighted	0.747	0.309	0.068	0.003
Oceanic whitetip	Variance-weighted	0.611	3.684	1.112	0.013
	Non-weighted	0.805	–0.051	0.009	0.001
Sandbar	Variance-weighted	0.461	3.688	1.508	0.044
	Non-weighted	0.075	–0.033	0.044	0.475

Yearly and Quarterly CPUE

For elasmobranchs as a group, yearly mean nominal CPUE was 12.04 elasmobranchs per 1,000 hooks, ranging from 8.67 (1996) to 14.99 (1998). For individual species, bootstrapped estimates of yearly mean CPUE were highly variable (Fig. 5), yet variance-weighted regression analysis indicated a significant decrease for night sharks (P<0.015), and a significant increase for oceanic whitetip (P<0.013) and sandbar sharks (P<0.044). However, regression analysis of non-weighted data for these three species produced slopes contrary to the weighted results (results not significant for sandbar) (Table 6).

For night sharks, we suggest the analyses are confounded by species identification problems. The weighting procedure used the inverse of the variance as a weight; thus, CPUE from years when observations were very rare and consequently had a low variance (such as 1992, 1993, and 1994 when only 1, 2, and 13 night sharks were observed, respectively) were weighted more heavily than CPUE from years when greater numbers were observed.

The weighting procedure we used assumes yearly variance is an estimate of precision, an assumption that is incorrect if species identification problems resulted in the low numbers of night sharks observed in the first few years. Sharks in the genus *Carcharhinus* are difficult to identify; we believe that these difficulties were likely more pronounced during the early years of the observer program before both observers and observer trainers gained experience with the variety of shark species encountered by this fishery. No such problem is suspected for the oceanic whitetip, where the large, rounded white-tipped fins present even an inexperienced observer with little identification difficulty. If the yearly variance in this case is a reasonable estimate of precision, the analysis suggests an increasing trend in the relative abundance of oceanic whitetips sharks.

These results serve to illustrate the substantial effect that weighting can have on the analysis of CPUE time series data. This is a common problem in stock assessment, where the choice of weights is an area of intense debate. The contradictory results of the nonweighted and weighted yearly CPUE regressions also need to be considered in view of the speculative nature of the relationship between CPUE and actual abundance.

[3]Beerkircher, L. Unpubl. data on file at Southeast Fisheries Science Center, NMFS, NOAA, Miami, FL 33149.

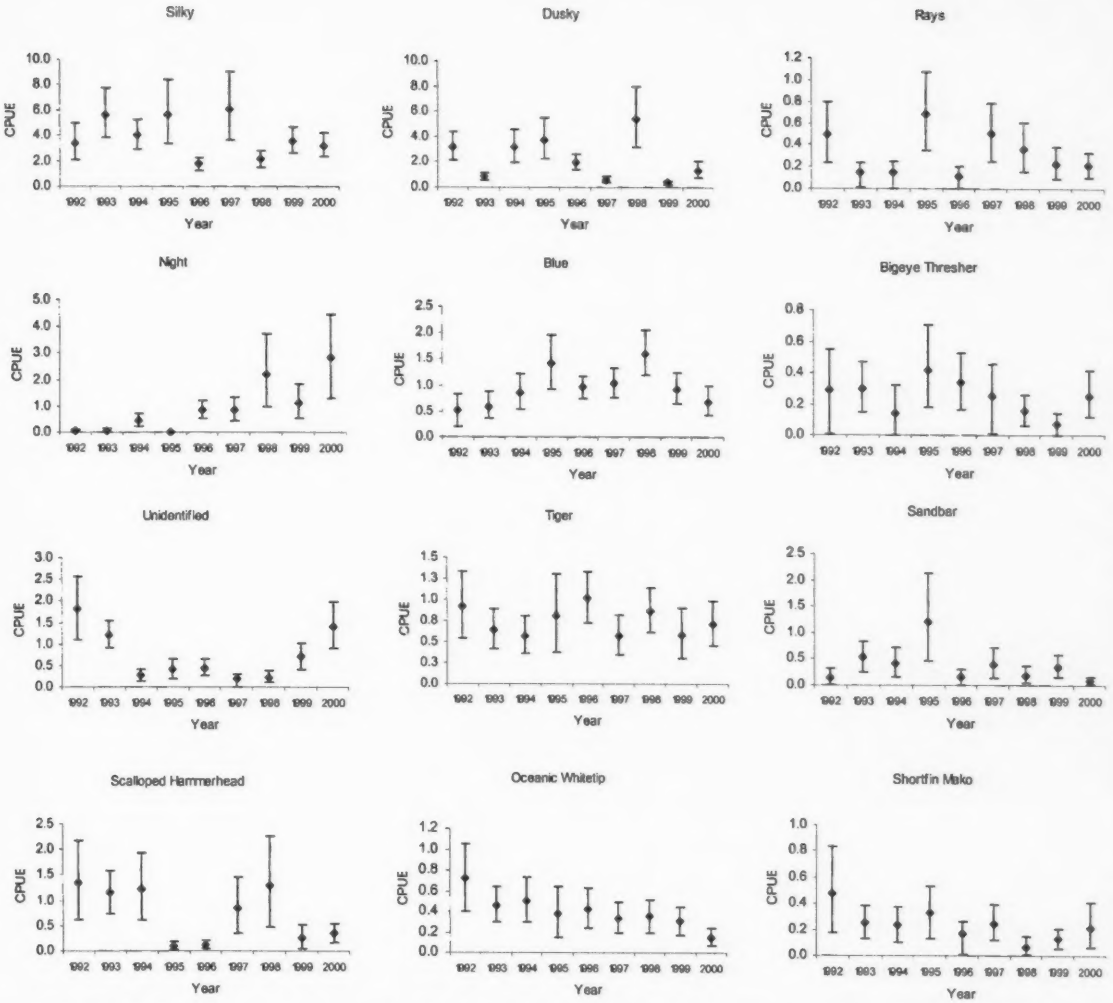

Figure 5. — Bootstrapped estimates by species of yearly mean catch per unit effort (CPUE) expressed as number caught per 1,000 hooks, 1992–2000. Vertical bars represent bootstrap 95% confidence limits.

Yearly CPUE trends, even highly significant ones, might not be indicative of real population change, but merely a result of spatial or gear changes in observed fishing effort. Additional years of data may help clarify any significant changes in CPUE; however, a more rigorous analytical approach, such as application of Generalized Linear Modeling, may also serve to account for factors not related to abundance but affecting CPUE.

To detect possible seasonal trends in CPUE, we analyzed the observer data by quarter. Quarterly overall elasmobranch CPUE varied from a high of 13.79 during quarter 2 (April–June) to a low of 9.73 in quarter 3 (July–Sept.), but the only significant ($P<0.004$) relationship was that elasmobranch CPUE in quarter 2 was greater than that in quarters 3 and 4 (Oct.–Dec.). For individual species, significant quarterly variation in CPUE was found for silky, night, blue, oceanic whitetip, rays, sandbar, and shortfin mako sharks (Table 7).

The higher relative abundance of blue sharks seen in quarters 1 and 2 reflects the occurrence of this species in the northern part of the study area (SAB) during the winter and spring. During these seasons the ocean temperature in the area (outside the Gulf Stream) is closer to the preferred temperature range of 10–20°C for blue sharks (Castro, 1983). In contrast to the blue shark, relative abundance of oceanic

Table 7.—Quarterly CPUE (numbers per 1,000 hooks) and significant relationships observed in the pelagic longline fishery off the southeastern U.S., 1992–2000.

Species	CPUE Qtr. 1	Qtr. 2	Qtr. 3	Qtr. 4	Quarterly relationship(s)	*P*
Silky	5.38	3.22	3.16	4.28	4>2	0.001
Dusky	1.50	3.09	1.94	1.10		
Night	1.48	1.62	0.30	0.28	1,2>3,4	0.0001
Blue	1.29	1.51	0.09	0.41	1,2>3,4	0.0001
Unidentified	0.58	1.04	0.63	0.62		
Tiger	0.57	0.64	0.93	0.87		
Scalloped hammerhead	0.63	0.83	0.78	0.62		
Oceanic whitetip	0.16	0.16	0.51	0.90	4>3>1,2	0.0001
Rays	0.28	0.09	0.45	0.49	4,3,1>2	0.0001
Sandbar	0.21	0.59	0.30	0.07	2>1,4	0.0002
Bigeye thresher	0.23	0.26	0.26	0.16		
Shortfin mako	0.41	0.19	0.18	0.16	1>2,3,4	0.01

Table 8.—Overall nominal CPUE (numbers caught per 1,000 hooks) off the southeastern U.S. Data for 1981–83 are from Berkeley and Campos (1988); 1992–2000 data are from this present study.

Species	CPUE 1981–83	1992–2000
Silky	11.22	3.49
Dusky	0.47	1.64
Night	10.75	1.36
Blue	0.60	1.05
Unidentified	0.87	0.66
Tiger	0.60	0.64
Scalloped hammerhead	13.37	0.48
Oceanic whitetip	0.87	0.32
Sandbar	0.07	0.28
Bigeye thresher	0.67	0.20
Shortfin mako	0.00	0.19

whitetips was greater in quarter 3, and particularly quarter 4, which may reflect this species' preference for warmer waters.

Relative abundance of night sharks was higher in quarters 1 and 2. This increase in night shark abundance from January through June was also described by Guitart-Manday (1975) for a fishery off the northwestern coast of Cuba. Relatively little is known about this species, and no published information is available that might help to explain the decrease in night shark abundance during July–December. Night sharks may remain in the study area but feed at greater depths than fishing occurs, or possibly migrate outside of the study area.

A paucity of comparable historical CPUE data for the study area makes comparisons with recent catch rates difficult. Berkeley and Campos (1988) provided the only fishery-dependent, but limited, observations of shark catch on similar gear during the early 1980's. Comparisons of overall nominal CPUE for sharks between the two sets of data are shown in Table 8. Large declines in relative abundance are seen for silky, night, and scalloped hammerhead sharks, and moderate increases are seen in dusky and blue sharks.

It should be noted, however, that several sampling differences exist between the two studies. Berkeley and Campos (1988) observed trips on vessels only in the Florida Straits (about lat. 25°N to 28°N), and there were at least some sets made in the Bahamian EEZ. The majority of the 111 sets made in the 1988 study were from a single vessel. Such significant spatial and vessel differences reduce direct comparability with the present data set, which is drawn from a much larger area and sampling effort from 65 different vessels.

An obvious spatial effect is the greater relative abundance of blue sharks noted in the present study. Blue sharks may be found in high numbers at certain times of the year in the South Atlantic Bight, but they are rarely seen in the warm waters between Florida and the Bahamas. It is possible that these or other biases also explain the other notable differences between the 1980's and 1990's data, but they may, in some cases, be indicative of real population declines.

Table 9.—Sex ratios of elasmobranchs observed in the pelagic longline fishery off the southeastern U.S., 1992–2000.

Species	Sample size Male	Female	Ratio Male	Female	Total no.
Silky	453	627	1.0	1.4	1,080
Dusky	236	231	1.0	1.0	467
Night	243	212	1.0	0.9	455
Blue	22	61	1.0	2.8	83
Tiger	25	49	1.0	2.0	74
Scalloped hammerhead	44	76	1.0	1.7	120
Oceanic whitetip	34	46	1.0	1.4	80
Rays	26	15	1.0	0.6	41
Sandbar	38	20	1.0	0.5	58
Bigeye thresher	24	19	1.0	0.8	43
Shortfin mako	41	23	1.0	0.6	64

Sex Ratio

Females dominated the catch for silky, blue, tiger, scalloped hammerhead, and oceanic whitetip sharks (Table 9). The gender dominance of female silky, scalloped hammerhead, and tiger sharks was observed previously in this area (Berkeley and Campos, 1988). Springer (1963), however, in data from an inshore bottom longline fishery, observed a more mixed (1:1) sex ratio for tiger sharks. These gender ratio differences for tiger sharks in different habitats may indicate the occurrence of some degree of gender segregation based on habitat type. The observation that female blue sharks were caught almost three times as often as males is consistent with reports of gender-biased segregation in this species (Pratt, 1979; Nakano and Nagasawa, 1996).

Analysis of the sex ratio by quarters indicated that although female silky sharks dominated in all quarters, there were significantly more males observed during the third quarter (χ^2= 9.71, df=3, P>0.05). Significant differences in sex ratios among quarters were also found for the blue shark, but the very low numbers of individuals observed during quarters 3 and 4 preclude any meaningful conclusions regarding seasonal distributions of the sexes.

Conclusions

Analysis of 9 years of observer bycatch data indicates that the characteristics of

sharks using the pelagic habitat off the southeastern United States vary greatly depending on the species, year, and season. The various degrees of seasonal abundance seen in these data are probably a reflection of the seasonal north-south or inshore-offshore migrations displayed by many species. Of concern is the indication that relative abundance of several shark species that utilize the pelagic habitat off the southeastern United States may have declined in the last 2 decades, and that the bulk of bycatch mortality was borne by individuals below size-at-maturity. For several of the observed species, examination of catch status suggests that bycatch mortality is not prevented by retention prohibitions.

While longline gear selectivity and a paucity of long-term, standardized catch and effort data may affect the robustness of inferences that can be drawn regarding population trends, these data serve as an important baseline for future shark surveys. Large portions of the study area have recently been closed to pelagic longline fishing to protect undersized swordfish, and the shark populations in this area may also benefit from these closures. However, area closures may not be effective when large portions of the populations they are designed to protect migrate into other areas where they are subject to fishing mortality. Since most of the sharks observed in this study are highly migratory in nature, close monitoring of this and surrounding areas will be needed for evidence that relatively small closures may benefit these populations.

Acknowledgments

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Spatial and Temporal Distribution of Sea Turtles in the Western North Atlantic and the U.S. Gulf of Mexico from Marine Recreational Fishery Statistics Survey (MRFSS)

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ABSTRACT—Systematic surveys, along with opportunistic sightings, have provided important information on sea turtle (Cheloniidae and Dermochelydae) distributions, knowledge which can help reduce the risk of harmful human interaction. In 1991 and 1992, the Marine Recreational Fishery Statistics Survey (MRFSS) of the National Marine Fisheries Service, NOAA, provided a unique opportunity to gain additional, synoptic information on the spatial and temporal distribution of sea turtles along the U.S. Atlantic and Gulf of Mexico coasts by asking recreational anglers if they had observed a sea turtle on their fishing trip. During the spring and summer months of those years, as water temperatures warmed, the MRFSS documented an increase in sea turtle sightings in inshore waters and in a northward direction along the U.S. Atlantic Coast and in a westward direction along the northern Gulf of Mexico. This pattern reversed in the late summer and fall months as water temperatures cooled, with sea turtles concentrating along Georgia and both coasts of Florida. Although the MRFSS did not provide species or size composition of sea turtles sighted, and effort varied depending upon location of fishing activity and time of year anglers were queried, it did provide an additional and useful means of ascertaining spatial and temporal distributions of sea turtles along these coasts.

Introduction

Limited data exist on sea turtle (Cheloniidae and Dermochelydae) distributions and seasonal patterns of movement, knowledge which can aid conservation managers in their efforts to protect sea turtles from potentially harmful human interaction (National Research Council, 1990). Systematic surveys (aerial, shipboard, strandings), in addition to opportunistic sightings by fishery observers and the general public, have been used to gather these important distributional data.

Since large areas can be covered in a relatively short time frame, aerial surveys are widely used (National Research Council, 1990; Henwood and Epperly, 1999). Although not as widely used, shipboard surveys also have been employed to obtain sea turtle seasonal distributions in areas up to 50 miles offshore (Lee and Palmer, 1981; Shoop and Kenney, 1992). Since 1980, the NOAA, National Marine Fisheries Service (NMFS), Sea Turtle Stranding and Salvage Network (STSSN) has been documenting the strandings of sea turtles along the U.S. Gulf of Mexico and Atlantic coasts (Schroeder, 1989) which can provide some insight into the spatial and temporal patterns of sea turtle distribution.

Sea turtle distribution also can be obtained through opportunistic observations of sea turtles. Recaptures of tagged turtles can provide valuable data on migration and seasonal distribution patterns (Henwood, 1987; Henwood and Ogren, 1987). Observers on commercial fishing vessels record position data for sea turtles incidentally captured in fishing gear, as well as for opportunistic ocean sightings (Henwood, 1987; Henwood and Ogren, 1987). Surveys of people likely to encounter sea turtles (recreational anglers and boaters, commercial fishermen) likewise have provided useful information regarding the distribution and movements of sea turtles (Carr et al., 1982; Epperly et al., 1995b).

Another potential source of such data is the NMFS Marine Recreational Fishery Statistics Survey (MRFSS) (http://www.st.nmfs.gov/st1/recreational/). In 1979, the NMFS initiated the MRFSS to estimate the impact of marine recreational fishing on marine resources along the Atlantic and Gulf of Mexico coasts of the United States (Essig and Holliday, 1991). Recreational fishing activity data are collected by interviewing a sample of recreational anglers fishing in coastal and ocean waters throughout the United States, with the exception of Texas which conducts a comparable, but separate, survey.

In 1991 and 1992, the MRFSS provided synoptic data on the spatio-temporal distribution of sea turtles by asking recreational anglers if they had observed a sea turtle on their fishing trip. This was the first such source of information covering the entire U.S. Atlantic and Gulf of Mexico coasts simultaneously. From those reported observations, we describe relative changes in seasonal abundance of sea turtles along both coasts.

Methods

The MRFSS utilizes, in part, interviews of anglers at fishing access sites as they return from their fishing trips (Essig

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and Holliday, 1991). Intercept interviews are used to collect catch and demographic data from anglers who have just completed a fishing trip from different modes of fishing: a charter/headboat, a private/rental boat, or from shore (pier, beaches, banks). As anglers complete their fishing trip they are asked to name the body of water in which they conducted most of their fishing activity and the number of hours that they fished. Bays, inlets, rivers, and sounds are scored as inshore waters. If they fished in the ocean, they are asked if they fished within (nearshore) or beyond (offshore) 5.6 km of shore.

Sampling effort along the gulf coast of Florida included inshore and offshore areas only. Sampling was conducted all days of the week, but most (75%) of the effort was on weekends and holidays. Due to low fishing effort, sampling was not conducted during January–February on the Atlantic coast north of Florida (except for North Carolina), and November–December for New Hampshire and Maine.

Sampling is stratified by state, mode of fishing, and wave (2-month sampling period) each year with a minimum of 30 interviews in each stratum. Interview effort may exceed this minimum, based on the average estimated fishing effort of the previous 3 survey years. Survey sampling sites, although randomly selected, are weighted by expected fishing activity.

Beginning in 1989, individuals fishing in North Carolina were asked if they had sighted sea turtles during their fishing trip. They were not asked to enumerate or identify the turtles sighted, just to indicate presence or absence of sea turtle sightings during their fishing trip. Multiple anglers on the same fishing boat or individual anglers on piers or jetties might report the same turtle.

In 1991 and 1992, this question was asked in all states participating in the MRFSS, which includes all states along the Atlantic and Gulf of Mexico coasts of the United States (excluding Texas). This question was not included in surveys after 1992.

After combining the data from both years, we calculated sightings per unit of effort (SPUE) for each state by dividing the total number of turtles sighted by the total number of hours fished for each wave (bimonthly period) and in each area. Sightings from charter, private/rental, and headboats may include those turtles sighted during transit time; however, since total number of hours fished (used to calculate SPUE) does not include transit time, this may result in an overestimation of these sightings.

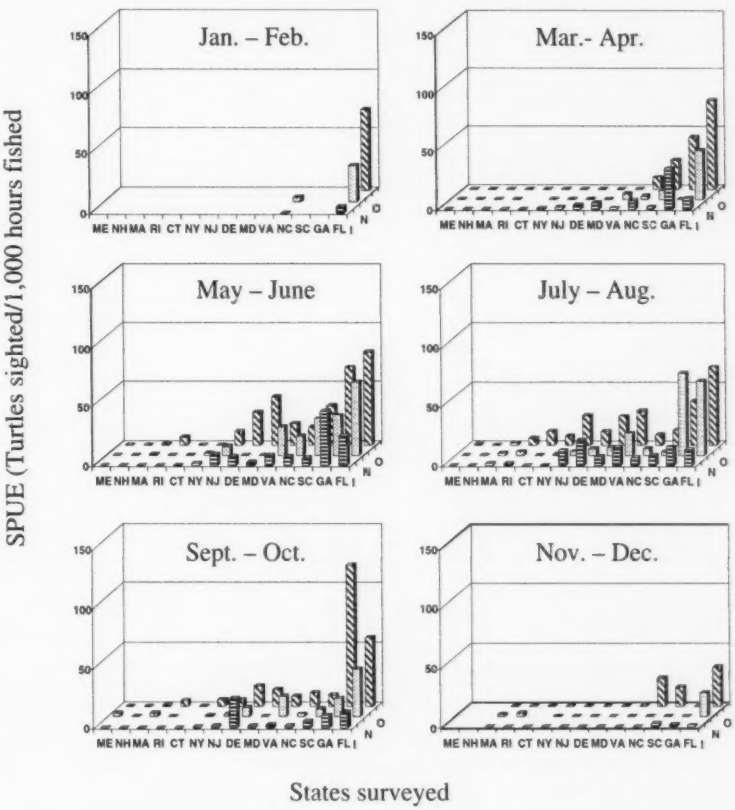

Figure 1.—Frequency distribution of sea turtles sighted by recreational anglers interviewed along the U.S. Atlantic coast during intercept interviews of the Marine Recreational Fishery Statistics Survey, 1991–92. Total number of sea turtle sightings/1,000 hours fished are given bimonthly for each state. Absence of data indicates no anglers were interviewed. I=Inshore; N=Nearshore; O=Offshore.

Results

The Marine Recreational Fishery Statistics Survey for the U.S. Atlantic and Gulf of Mexico states (excluding Texas) interviewed 74,007 anglers in 1991 and 90,596 in 1992, representing a total of about 700,000 h of fishing activity (Tables 1, 2). Of these anglers, about 4.5% reported sighting a live sea turtle while fishing.

U.S. Atlantic Sightings

January–February

During January and February, sea turtles were observed in North Carolina's nearshore waters and in Florida's nearshore and offshore waters (Table 1, Fig. 1). However, MRFSS survey effort was lacking in all other states. The sighting rates of sea turtles was greatest in the nearshore and offshore waters of Florida.

Table 1.—Effort of recreational anglers interviewed along the Atlantic Coast during intercept interviews of the Marine Recreational Fishery Statistics Survey, 1991–1992. Total number of hours fished and interviews (in parentheses) are given bimonthly for each state and area fished. Absence of data indicates no survey effort.

State	Distance from shore	Total number of hours fished (number of interviews)					
		Jan–Feb	Mar–Apr	May–Jun	Jul–Aug	Sep–Oct	Nov–Dec
Maine	Inshore		28.0 (15)	412.0 (148)	936.0 (326)	593.5 (213)	
	Nearshore		82.5 (41)	210.0 (80)	639.0 (213)	332.5 (116)	
	Offshore		469.5 (102)	832.0 (192)	1009.5 (262)	537.5 (118)	
New Hampshire	Inshore		13.0 (9)	299.5 (88)	627.5 (154)	161.0 (58)	
	Nearshore		63.5 (36)	190.0 (76)	178.0 (58)	220.5 (76)	
	Offshore		796.5 (181)	734.5 (173)	720.0 (179)	381.0 (77)	
Massachusetts	Inshore		666.5 (247)	3,632.5 (1078)	6,607.5 (1835)	5,895.5 (1567)	1,103.5 (325)
	Nearshore		361.0 (127)	4,003.5 (1223)	7,687.5 (2354)	5,373.0 (1456)	469.5 (165)
	Offshore		923.5 (213)	3,142.5 (663)	3,791.5 (943)	2,677.5 (582)	690.5 (142)
Rhode Island	Inshore		426.0 (131)	2,836.0 (870)	4,096.0 (1241)	3,841.0 (1066)	609.5 (153)
	Nearshore		81.0 (34)	559.0 (140)	2,531.0 (698)	2,297.5 (586)	723.5 (187)
	Offshore		694.0 (138)	1,089.0 (218)	2,835.0 (553)	3,043.5 (566)	1,077.0 (188)
Connecticut	Inshore		684.5 (190)	4,090.0 (1200)	7,152.0 (1918)	4,962.0 (1389)	645.5 (176)
	Nearshore			30.0 (4)	7.0 (2)		
	Offshore		278.5 (70)	424.5 (81)	455.0 (85)	353.0 (54)	28.5 (9)
New York	Inshore		6,074.5 (1459)	12,826.0 (3085)	18,838.0 (4566)	14,474.5 (3531)	3,361.0 (864)
	Nearshore		1,464.5 (309)	3,499.5 (792)	4,656.5 (1016)	5,739.0 (1241)	3,547.0 (725)
	Offshore		464.0 (81)	1,402.0 (212)	2,684.5 (419)	2,220.5 (320)	818.5 (151)
New Jersey	Inshore		1,125.5 (295)	4,784.5 (1219)	6,250.0 (1536)	6,557.0 (1785)	1,113.0 (314)
	Nearshore		163.5 (40)	3,154.5 (735)	5,186.0 (1271)	11,901.5 (2923)	4,631.0 (1094)
	Offshore		890.0 (153)	2,063.0 (498)	2,949.0 (568)	2,017.0 (370)	630.0 (131)
Delaware	Inshore		802.0 (248)	6,428.0 (1350)	10,928.0 (2396)	4,327.5 (919)	604.5 (183)
	Nearshore		46.0 (15)	235.0 (54)	552.0 (114)	489.0 (102)	311.0 (76)
	Offshore		688.5 (165)	849.5 (155)	2,065.0 (290)	532.0 (79)	250.0 (53)
Maryland	Inshore		2,016.5 (567)	5,047.5 (1269)	6,960.0 (1675)	5,467.5 (1309)	494.0 (159)
	Nearshore		39.5 (15)	96.0 (26)	158.0 (49)	105.0 (30)	163.5 (48)
	Offshore		557.5 (166)	365.5 (94)	1,037.5 (205)	287.5 (76)	285.5 (87)
Virginia	Inshore		1,502.0 (348)	5,860.5 (1225)	4,926.5 (1033)	3,935.5 (754)	1,030.5 (261)
	Nearshore		460.5 (101)	1,097.5 (243)	1,308.0 (303)	569.0 (141)	62.0 (18)
	Offshore		486.0 (111)	790.0 (164)	882.0 (167)	718.0 (107)	364.5 (72)
North Carolina	Inshore	18.5 (5)	1,098.0 (295)	6,630.5 (1601)	4,717.2 (1101)	7,450.5 (1675)	3,095.0 (699)
	Nearshore	543.0 (197)	5,938.0 (1443)	19,301.5 (4377)	17,911.8 (4163)	17,716.5 (3891)	10,285.0 (2402)
	Offshore		2,717.0 (438)	12,932.0 (2074)	12,329.0 (1953)	11,420.0 (1847)	1,726.5 (283)
South Carolina	Inshore		843.0 (218)	2,419.3 (468)	2,142.0 (461)	1,794.8 (368)	2,398.5 (502)
	Nearshore		397.8 (75)	942.5 (189)	736.5 (145)	904.5 (191)	479.5 (94)
	Offshore		728.5 (104)	1,215.5 (194)	1,587.0 (232)	1,310.0 (196)	444.5 (86)
Georgia	Inshore		2,240.5 (647)	2,375.5 (618)	1,916.5 (493)	2,428.5 (560)	2,679.5 (625)
	Nearshore		171.5 (41)	208.0 (53)	390.5 (90)	191.0 (54)	242.0 (51)
	Offshore		180.0 (38)	742.5 (144)	679.0 (129)	144.0 (30)	12.0 (2)
Florida–East Coast	Inshore	3,932.5 (1153)	4,361.0 (1353)	4,940.0 (1369)	3,243.0 (937)	3,690.0 (1026)	5,220.0 (1546)
	Nearshore	3,113.5 (810)	4,032.5 (1190)	3,511.5 (890)	5,883.0 (1584)	3,296.0 (839)	2,968.5 (791)
	Offshore	1,899 (380)	2,657.5 (597)	4,365.0 (982)	5,776.5 (1251)	2,249.0 (480)	1,252.5 (272)

March–April

During this period, MRFSS surveys were conducted from Florida to Maine. However, sighting rates were highest from the southern states (North Carolina to Florida), in particular, from Florida's nearshore and offshore waters (Table 1, Fig. 1). Sea turtles were observed in inshore waters as far north as New York, but in relatively low numbers. The most notable exception was Georgia, where the sighting rate of sea turtles in inshore waters was comparable to South Carolina, Georgia, and Florida nearshore and offshore sighting rates (Fig. 1). Although anglers from New York, New Jersey, Delaware, and Maryland only reported sea turtle sightings from inshore waters, fishing effort there was considerably higher than in the nearshore or offshore waters (Table 1).

May–June

Sea turtle sighting rates during May and June increased considerably from New Jersey to Florida with some nearshore and offshore sightings reported from as far north as Rhode Island and Massachusetts (Fig. 1). Inshore sightings had progressed north to Connecticut, but sighting rates were highest in Georgia and Florida. Nearshore sighting rates increased substantially in Virginia (from 4.3 to 23.7), North Carolina (from 2.9 to 15.6), South Carolina (from 7.5 to 30.8), and Georgia (from 0.0 to 33.7). Offshore sighting rates increased in Georgia, South Carolina, and North Carolina, and turtles were reported for the first time in Virginia, Maryland, Delaware, and New Jersey's offshore waters. It is interesting to note that Maryland's offshore sighting rates were exceeded only by Georgia's and Florida's.

July–August

With the exception of New Hampshire, sea turtles were observed from Maine to Florida during July and August and were reported from the inshore waters of Massachusetts and Rhode Island for the first time (Fig. 1). The highest sighting rate for inshore waters occurred in New Jersey, Delaware, Virginia, Georgia, and Florida; however, inshore sighting rates from Georgia and Florida decreased by

Table 2.—Effort of recreational anglers interviewed along the Gulf Coast during intercept interviews of the Marine Recreational Fishery Statistics Survey, 1991–92. Total number of hours fished and interviews (in parentheses) are given bimonthly for each state and area fished. Absence of data indicates no survey effort. Texas is not included in the survey.

State	Distance from shore	Total number of hours fished (number of interviews)					
		Jan–Feb	Mar–Apr	May–Jun	Jul–Aug	Sep–Oct	Nov–Dec
Louisiana	Inshore	2,352.0 (623)	2,990.0 (697)	4,076.0 (991)	3,255.0 (769)	4,173.0 (967)	4,929.0 (1055)
	Nearshore	854.0 (193)	1,552.5 (326)	1,794.0 (383)	3,114.5 (705)	1,427.0 (306)	452.5 (99)
	Offshore	436.5 (89)	986.0 (183)	1,179.0 (196)	1,102.5 (198)	1,311.5 (247)	258.5 (51)
Mississippi	Inshore	436.5 (160)	1,333.0 (383)	1,307.0 (296)	1,648.0 (382)	1,903.5 (455)	983.5 (258)
	Nearshore	231.0 (71)	479.5 (134)	1,271.0 (325)	534.5 (140)	802.0 (219)	715.0 (216)
	Offshore	182.5 (35)	395.0 (73)	1,136.0 (193)	2,564.5 (398)	1,850.5 (313)	413.5 (106)
Alabama	Inshore	261.0 (83)	572.5 (193)	575.5 (130)	327.5 (94)	419.5 (115)	791.0 (213)
	Nearshore	596.0 (179)	974.5 (278)	1,122.0 (275)	1,313.0 (341)	889.0 (241)	622.5 (162)
	Offshore	559.5 (150)	933.5 (228)	1,860.5 (437)	1,615.0 (345)	1,827.0 (425)	1,093.0 (286)
Florida–West Coast	Inshore	4,906.0 (1385)	5,844.5 (1577)	5,049.5 (1370)	3,183.1 (816)	5,712.5 (1501)	5,464.0 (1414)
	Nearshore						
	Offshore	5,795.5 (1304)	8,765.0 (2038)	9,045.5 (2108)	7,042.5 (1649)	8,555.5 (2019)	5,725.5 (1408)

50% or more from the previous wave (bimonthly period). Sea turtles were sighted for the first time in the nearshore waters of Rhode Island, Delaware, and Maryland. Offshore sighting rates in New Jersey, Maryland, and Virginia were only slightly lower than off Georgia.

September–October

There was a notable decrease in sea turtle sighting rates during September and October for most of the northern states (Maine to Virginia) and a shift from inshore to offshore sightings, with a few notable exceptions (Fig. 1). While most states showed a decrease in inshore sighting rates, Delaware showed an increase, surpassing all other states, despite a decrease in fishing effort. Maine, Massachusetts, New York, and Delaware had slight to moderate increases in nearshore sighting rates, but the greatest sighting rates were from Virginia southward. Finally, all states north of North Carolina showed decreases in offshore sighting rates with the exception of Delaware which showed a slight increase.

November–December

With a few exceptions, no sea turtles were sighted north of North Carolina during this period (Fig. 1). (No MRFSS survey effort was present in Maine, New Hampshire, or the nearshore waters of Connecticut.) Sea turtle sighting rates decreased in inshore and nearshore waters from North Carolina to Florida. Offshore sighting rates from North and South Carolina increased, but they decreased from Georgia and Florida; however, only two anglers fishing in Georgia's offshore waters were queried (Table 1).

U.S. Gulf of Mexico Sightings

January–February

Sea turtles were sighted only in the offshore waters of Florida and Alabama, and the inshore waters of Florida during January and February (Fig. 2). Offshore sighting rates from Florida (29.2) and Alabama (21.4) were almost ten-fold greater than Florida's inshore rates (4.7). There was no MRFSS survey effort in Florida's nearshore waters.

March–April

Sea turtles were sighted in all areas during this period except Mississippi inshore waters (Fig. 2). Sighting rates were greater in the eastern Gulf of Mexico than the western; Florida had the highest inshore sighting rates followed by Alabama. Sighting rates from Florida (28.0) and Alabama (15.0) offshore waters exceeded those from both Mississippi (10.3) and Louisiana (1.0).

May–June

Sea turtle sighting rates increased or remained comparable from previous months in all areas (Fig. 2). Offshore sighting rates from all states exceeded their nearshore and inshore sighting rates. Mississippi nearshore sighting rates (11.8) had increased nearly ten-fold from the previous months (2.1) and exceeded all other states' inshore and nearshore waters sighting rates. Sighting rates from Louisiana were less than those from any other Gulf state for all waters and remained relatively unchanged or only slightly increased from the previous months' sighting rates.

July–August

With a few exceptions, sighting rates decreased for all waters during this period (Fig. 2). Sighting rates from Florida inshore waters greatly exceeded inshore sighting rates from any other Gulf state. Alabama had a 50% reduction in its nearshore sighting rates from the previous wave while Mississippi nearshore sighting rates dropped from 11.8 to 0. Although sighting rates from Louisiana offshore waters had increased slightly from the previous wave, they were still less than 50% of the sighting rates from either Alabama or Florida offshore waters.

September–October

Sighting rates decreased again for all states in all waters with the exception of Mississippi nearshore and Louisiana and Alabama inshore waters which showed increases (Fig. 2). Interestingly, Alabama and Louisiana inshore sighting rates peaked during this time period when most of the other states and other areas were demonstrating a reduction in sea turtle sighting rates.

November–December

Sea turtles were sighted only in the offshore waters of Florida and Alabama, the inshore waters of Florida, and the nearshore waters of Mississippi during this period. These were very similar to

the sighting patterns from January and February (Fig. 2). Sighting rates from all states and all waters had decreased again in November and December with the exception of Alabama which had an increase in its offshore sighting rate.

Discussion

Atlantic

With the exception of most states during January and February, and Maine and New Hampshire in November and December, MRFSS survey effort was present along U.S. Atlantic coast states at all times for all waters. As waters warmed during the spring and early summer months (March–June), sea turtle sighting rates increased in a northward direction and into nearshore and inshore waters. This pattern was reversed during the late summer and fall months (July–October), presumably as waters cooled.

Aerial surveys conducted along the U.S. Atlantic coast from Florida to Massachusetts (Witzell and Azarovitz, 1996), as well as those conducted along the northeastern (Shoop and Kenney, 1992) and southeastern United States (Thompson and Huang, 1993; Musick et al., 1994; Thompson[1]), revealed a similar pattern of movement. Sighting densities increased during the spring and summer months (Shoop and Kenney, 1992; Thompson and Huang, 1993; Witzell and Azarovitz, 1996; Thompson[1]). By the spring, loggerhead sea turtles, *Caretta caretta*, were sighted as far north as Delaware Bay and leatherback sea turtles, *Dermochelys coriacea*, were more widely distributed farther north (Shoop and Kenney, 1992). Aerial surveys of the Middle Atlantic States demonstrated densities of loggerheads to be greatest south of Cape Hatteras in April but by May, densities were highest north of the Cape (Musick et al., 1994). During the summer, sightings documented by aerial surveys increased but were more concentrated in certain areas. Sea turtles in the northern part of the United States were mainly distributed between Cape Hatteras, N.C., and Long Island, N.Y., (Shoop and Kenney, 1992) while surveys in the southeastern United States waters revealed sea turtles mainly distributed off Florida (Thompson and Huang, 1993; Thompson[1]). By fall, sightings had decreased with most sea turtles observed in the southern part of the study area, with a more random distribution (Shoop and Kenney, 1992; Thompson and Huang, 1993; Witzell and Azarovitz, 1996).

Likewise, long-distance recapture records of immature loggerheads from the nearshore waters of Cape Canaveral, Fla., indicated a northward movement toward warming waters during the spring and summer (Henwood, 1987; Schmid, 1995). Of 475 recaptured immature loggerheads tagged in the vicinity of Cape Canaveral, Fla., 29 were recaptured more than 100 n.mi. from the study area, mostly to the north in the coastal waters of Georgia, the Carolinas, and Virginia (Henwood, 1987). Most of these long-distance recaptures (22 of 29) were initially tagged in the Cape Canaveral

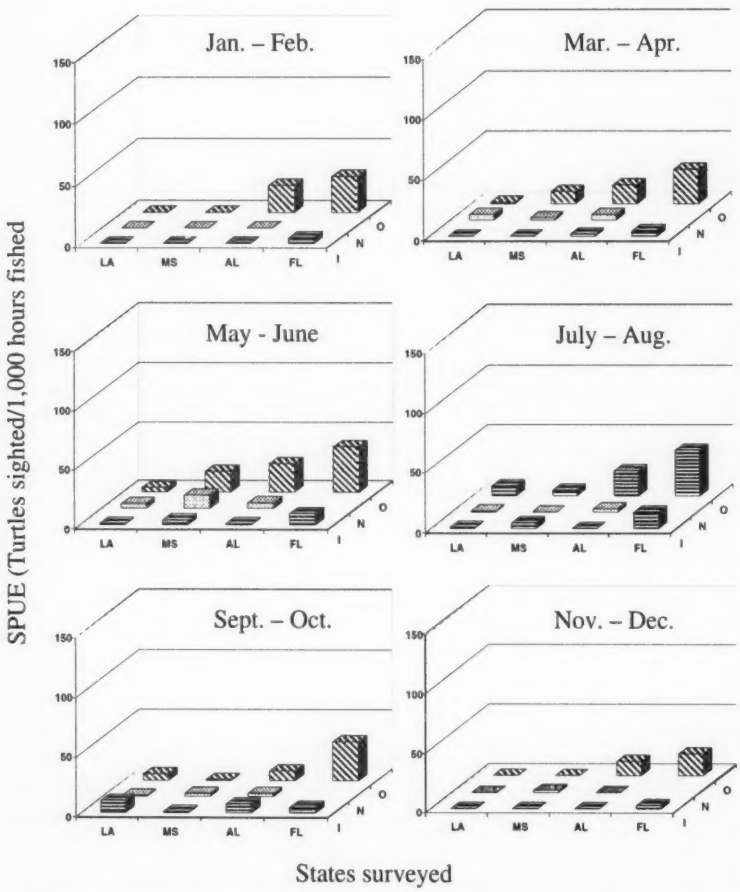

Figure 2.—Frequency distribution of sea turtles sighted by recreational anglers interviewed along the U.S. Gulf of Mexico coast during intercept interviews of the Marine Recreational Fishery Statistics Survey, 1991–92. Total number of sea turtle sightings/1,000 h fished are given bimonthly for each state. Absence of data indicates no anglers were interviewed. Texas is not included in the survey. I=Inshore; N=Nearshore; O=Offshore.

[1]Thompson, N. B. 1984. Progress report on estimating density and abundance of marine turtles: results of first year pelagic surveys in the southeast U.S., 60 p. Unpubl. data on file at NOAA, NMFS Southeast Fisheries Science Center, 75 Virginia Beach Dr., Miami, FL 33149.

area from October to March, while a majority (27 of 29) were recaptured from May to September. In addition, sea turtles initially tagged from Long Island Sound, N.Y., have been recovered as far south as South Carolina and Florida in the same year, suggesting a southward movement (Morreale and Standora, 1995).

The MRFSS documented turtle sightings during late fall and early winter months (November–December) to be mainly from offshore waters. The only inshore sightings during that time were from North Carolina to Florida. Emigration from sounds, bays, and other inshore waters also has been documented through aerial surveys and mark-recapture studies in Delaware (Spotila[2]), Virginia (Keinath et al., 1987), and North Carolina (Epperly et al., 1995a; Epperly et al., 1995b). Sea turtles had emigrated from the inshore waters of Delaware by September, Virginia by November, and North Carolina by December.

MRFSS sighting rates from all Atlantic Coast states peaked from May to August; however, southern states (North Carolina to Florida) demonstrated this peak during May and June while northern state (Virginia to Maine) sightings peaked during July and August. Similarly, aerial surveys of the Atlantic coast noted a peak in turtle densities from Cape Hatteras, N.C., to Cape Cod, Mass., in July and August (Witzell and Azarovitz, 1996), with the majority of sightings from aerial surveys of the northeast United States occurring from Cape Hatteras, N.C., to Long Island, N.Y., during the summer (Shoop and Kenney, 1992). Likewise, during 1991 and 1992, the STSSN reported peaks in strandings for the southeast United States (Atlantic coast of Florida to North Carolina) from April to July and in the northeast United States (Virginia to Maine) from June to August (Teas[3]).

In addition, the MRFSS documented turtle sighting rates from Delaware inshore waters that were comparable to or greater than those for Maryland, Virginia, North Carolina, and South Carolina during the months of May to October (Fig. 1). Similarly, aerial surveys revealed that sea turtles inhabit Delaware Bay from June through September at densities similar to those reported for Virginia, North Carolina, and Georgia (Spotila[2]).

U.S. Gulf of Mexico

In the Gulf of Mexico, MRFSS survey effort was present at all times for all areas except the nearshore waters of Florida and for all of Texas. Similar to the Atlantic coast states, sighting rates increased in the nearshore and inshore waters during the spring and early summer months, peaking during the months of May to August, but the movement of the increase appeared to be in a westward direction. This pattern was reversed during the late summer and fall months with turtle sighting rates greatest from offshore waters on the eastern side of the Gulf of Mexico during late fall and winter months. However, since the MRFSS did not sample Texas, we do not know the sighting rate for the western section of the Gulf of Mexico or if this pattern of movement was evident there as well.

Aerial surveys of the Gulf of Mexico noted similar peaks in density. Lohoefener et al. (1988) estimated greater hard-shelled sea turtle densities from aerial surveys conducted April through July than those conducted September to December. Fritts et al. (1983) sighted the highest number of loggerheads in April and the lowest number in December. Likewise, from 1991 to 1992, strandings in the Gulf of Mexico (Texas to the Florida Gulf coast) peaked in April, July, and August (Teas[3]). In contrast, Thompson et al. (1991) reported more sightings in the fall (September and October) than the summer (June to August).

Aerial surveys of the Gulf of Mexico have revealed lower turtle densities from the western side of the Gulf than the eastern (Fritts et al., 1983; Lohoefener et al., 1988; Thompson et al., 1991). According to Fritts et al. (1983), loggerheads were 50 times more abundant in the waters off of western Florida than off of Louisiana and Texas. Likewise, the MRFSS documented the fewest turtle sightings in Louisiana (Texas was not included in the survey) with the greatest sightings along the gulf coast of Florida. In contrast, the number of strandings from Texas (41%) were comparable to those from the gulf coast of Florida (48%) (Teas[3]). Overall, MRFSS sightings from Louisiana were low compared to the other Gulf of Mexico states, similar to what Lohoefener et al. (1988) reported from aerial surveys. Similar to the eastern coast of Florida, the MRFSS documented the presence of sea turtles off the western coast of Florida at all times of the year.

No methodology of obtaining sea turtle distributional data is without limitations. Glare, lack of water clarity, observer inexperience (Henwood and Epperly, 1999), and the limited (3.8–41%) time turtles spend on the surface (Kemmerer et al., 1983; Keinath et al., 1987; Byles, 1989) can impact an observer's ability to sight a turtle during an aerial survey. Sea surface conditions (Lee and Palmer, 1981) and a more confined area of coverage (due to the observer's close proximity to the water's surface) also can restrict the distributional data shipboard surveys can collect. The possibility that a dead sea turtle might drift some distance before washing up on shore and lack of consistent effort along all shorelines are limitations of sea turtle strandings providing distributional data. Finally, it can take years of labor-intensive effort before mark-recapture data depict the spatio-temporal distributions of sea turtles.

Likewise, the MRFSS is not without its limitations. The MRFSS does not provide species or size composition of sea turtles sighted, and effort varies depending upon location of fishing activity and time of year anglers are queried.

Despite these limitations, the information gained from the interviews of anglers can be used to corroborate or supplement distributional data obtained from more systematic (aerial, shipboard, strandings) or other opportunistic (mark-recapture, reports of sea turtle sightings by the general public or commercial fishermen) surveys. In addition, the MRFSS is the only

[2]Spotila, J. R., P. T. Plotkin, and J. A. Keinath. Unpubl. In-water population survey of sea turtles of Delaware Bay. Final report to NMFS Office Prot. Resour., Silver Spring, Md., 21 p. Drexel Univ., 3141 Chestnut St., Philadephia, PA 19104.

[3]Teas, W. Unpubl. data in 1992 annual report of the Sea Turtle Stranding and Salvage Network, Atlantic and Gulf Coasts of the United States, Jan.–Dec. 1992, p. 1–43. NOAA, NMFS Southeast Fisheries Science Center, 75 Virginia Beach Dr., Miami, FL 33149.

methodology that provides a means of ascertaining synoptic distributional data of sea turtles simultaneously along both the Atlantic and Gulf of Mexico coasts (from Maine to Louisiana) for inshore waters as well as offshore waters out to the Exclusive Economic Zone.

The "turtle question" has not been included in the MRFSS since 1992. Because of the valuable sea turtle distributional data that can be obtained from asking anglers this question, we recommend that its inclusion in the MRFSS program be revisited.

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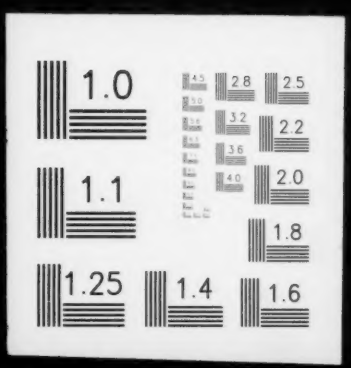
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